# IN-DEPTH SURVEY REPORT:

# FIELD EVALUATION OF BLAW-KNOX PROTOTYPE ENGINEERING CONTROLS DESIGNED TO REDUCE OCCUPATIONAL EXPOSURES DURING ASPHALT PAVING OPERATIONS

MANUFACTURER Blaw-Knox, Inc
PAVING CONTRACTOR Spartan Paving

PAVING LOCATION: Shiawassee County, Michigan

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Public Health Service
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| PLANT SURVEYED | Blaw-Knox, Inc (Paver Manufacturer)<br>Spartan Paving (Paving Contractor)<br>Shiawassee County, Michigan |
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# DISCLAIMER

# EXECUTIVE SUMMARY

On July 15-20, 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 Blaw-Knox 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 evaluations, NIOSH researchers focused primarily on each engineering control's ability to capture and remove airborne contaminates generated within the asphalt paver's auger area Secondary measurements were collected at screed and paver operator positions located on the asphalt paver Since no prescribed methods exist to evaluate engineering controls under the unique physical constraints of the asphalt paving environment, the NIOSH researchers developed a multifaceted evaluation strategy that included tracer gas testing, industrial hygiene sampling, real-time sampling for particulate (PM10), organic vapor, wind speed, 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 Blaw-Knox phase two (field) evaluation of a single engineering control installed on a Blaw-Knox Model PF5510 asphalt paving machine The tested design consisted of two slot-type exhaust hoods (one per side) mounted to the rear of the tractor and above the auger area The two hoods were connected via ducting to a single hydraulic exhaust fan The exhaust fan's stack exhausted the captured air and contaminants approximately 8 feet above the paver deck and approximately 14 feet above the ground

Field tracer gas measurement techniques revealed an average exhaust flow of 1630 cubic feet per minute (cfm) from the exhaust fan and 84 percent capture efficiency Test results collected

directly above the paver auger indicated that the Blaw-Knox engineering control was successful in capturing and removing an average of 53 percent of the asphalt fume released from the auger area This source reduction contributed to an average worker-area reduction of roughly 50 percent when evaluated at the screed operator and paver operator positions 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%) concentrations at the screed operator and paver operator positions Using this approach, the Blaw-Knox engineering control produced an average reduction in higher-level exposures of 67 percent within these workstations

Blaw-Knox engineers requested NIOSH to test an alternate field configuration of the engineering control that is considered to be proprietary at this point Although only tested for a single testing period in this configuration, the point estimates showed that the proprietary configuration could raise capture efficiencies of auger area fume to over 90 percent

The Blaw-Knox evaluation was the second of six field evaluations to be conducted as part of the engineering controls research partnership The testing methods used had only a minimal history in environments as unique and physically demanding as the asphalt paving environment Knowledge gained during this evaluation resulted in limited changes to the evaluation protocol and potentially impacted the findings of subsequent performance evaluations Lastly, many of the environmental and process variables were unique to the Blaw-Knox evaluation For example, inclement weather on day 3 resulted in equipment failures and shortages of sampling media that limited the total number of successfully collected data points during the Blaw-Knox evaluation For all of these reasons, the reported performance results should not be used to predict future results under different conditions or to compare performances with those obtained by other paver manufacturers

The implementation of engineering controls on asphalt paving equipment will continue to be an iterative process As this process continues, NIOSH recommendations to Blaw-Knox include (1) 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, (2) Modify or supplement the existing hood design with an increased level of enclosure to improve fume capture from the auger area and minimize escaping fume when the screed is extended beyond the width of the paver

# INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), a Federal agency located in the Centers for Disease Control and Prevention under the Department of Health and Human Services, was established by the Occupational Safety and Health Act of 1970 This legislation mandated NIOSH to conduct research and educational programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards

The Engineering and Physical Hazards Branch (EPHB) (formerly the Engineering Control Technology Branch) of the Division of Applied Research and Technology (DART) (formerly the Division of Physical Sciences and Engineering) has the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness Since 1976, EPHB has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique The objective of each of these studies has been to identify or design engineering control techniques and to evaluate their effectiveness in reducing potential health hazards in an industry or at specific processes Information on effective control strategies is subsequently published and distributed throughout the affected industry and to the occupational safety and health community

# BACKGROUND

On July 15-20, 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 Blaw-Knox 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 this 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 Blaw-Knox phase one evaluation occurred in July 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 Blaw-Knox Construction Equipment Corporation, Mattoon, IL"[2]  Since the phase one evaluation was only one portion of the overall development and evaluation of the Blaw-Knox engineering control, finalization of the Blaw-Knox phase one report was delayed until the completion and release of the Blaw-Knox phase two report

The scope of this report is the Blaw-Knox phase two (field) evaluation of a prototype engineering control installed on a Blaw-Knox Model PF5510 (see Figure 1) asphalt paving machine  Participating NIOSH researchers included Ken Mead, Mechanical Engineer, Leroy Mickelsen, Chemical Engineer, Stan Shulman, Statistician, Clint Morley, Intern-Industrial Hygienist, Jack Hill, Intern-Industrial Hygiene technician, and Erica Baker, student intern, all from DART, NIOSH  The NIOSH team was augmented by Tom Brumagin, NAPA's Director of Environmental Services, Tom Skinner, Blaw-Knox Manager of Product Support, Leland Warren, Blaw-Knox Design Engineer, David James, Blaw-Knox engineer, and Jim Legner, Blaw-Knox engineering technician  The field evaluation was conducted in coordination with Michigan paving contractor, Spartan Paving at a Spartan project site in Shiawassee County, Michigan  Representatives for Spartan Paving included Mr  Charles Van Deusen (subcontracted from Payne & Dolan, Inc.), Mr  Richard Brilhart, area superintendent, and Mr  Myron Bodel, paving crew foreman

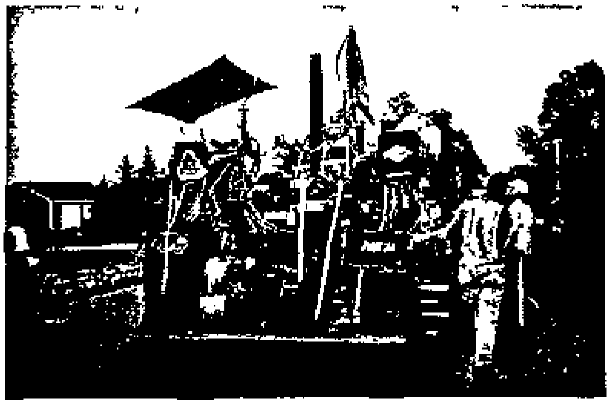

**FIGURE 1.** Blaw-Knox Model PF5510 asphalt paving machine undergoing field testing of prototype engineering controls  The testing site was a county paving project in Shiawassee County, Michigan

# 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 ($1 \times 10^{-6}$ meters) and smaller A secondary focus was on the control of organic vapors originating from the hot mix asphalt (HMA) Since no prescribed methods existed to evaluate engineering controls under the unique physical constraints of the asphalt paving environment, a multifaceted protocol, using multiple evaluation methods, was developed to quantify each engineering control's performance (Appendix A) Each of the evaluation methods within the protocol has inherent advantages and disadvantages, some of which can have an effect on the calculated results An additional advantage of using multiple evaluation methods was that, at times, the harsh environment led to equipment malfunctions and the loss of important data The impact of these losses was lessened by the presence of multiple evaluation tools It was anticipated that some of these methods would work better than others and that as the overall project progressed, adjustments would be made to selection and application of the evaluation methods based upon prior experiences

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 hoods would have affected the overall performance evaluation results During the first test period on the third full day of sampling the engineering control was tested in an alternate configuration that included additional auger enclosure Only the real-time monitoring methods were used during this period The results were not considered in the overall calculation of performance results for the Blaw-Knox engineering control and are presented separately in this report

Since the control settings were alternated, the only condition that was randomized was the initial setting for the given day However, the evaluation plan also specified that if day 1 started with control-on then the following day would start with control-off, and vice-versa Further details concerning the statistical design and randomization strategy for the real-time and industrial hygiene samples is included in Appendix B A listing and description of the different evaluation methods follows

**Tracer Gas:** For the phase two (field) evaluations, the tracer gas evaluation technique from phase one was modified for use during actual paving operations The method to calculate total exhaust flow of the engineering control did not deviate from the phase one tracer gas method However, the capture efficiency $SF_6$ dosing technique required modification for use when paving Instead of supplying $SF_6$ to the auger area via a distribution plenum under the auger, the $SF_6$ was supplied through four medical-quality 20-gauge injection needles, uniformly distributed across the width of the auger The intent of this dosing system was to deliver the $SF_6$ into the open head space near the top of the auger area (above the fresh HMA and between the front of the screed and the rear of the tractor) The four needles were positioned at a level approximate to the top of the screed and pointed down toward the center of the auger 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 from the auger head space For the Blaw-Knox evaluation, the total dosing flow of $SF_6$ was approximately 0 15 liters per minute (lpm) for each needle (0 3 lpm per side) Multiple tests were conducted during each control-on test period Difficulties encountered with the field tracer gas method included maintaining the sampling wand at the desired orientation within the exhaust duct and preventing needle obstruction due to occasional contact with the HMA

**Industrial Hygiene Sampling:** Industrial hygiene (IH) sampling trains were configured for use with two analytical sampling methods The first method collected and quantified total particulate onto a single filter 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 directly above the auger and at each of the asphalt paver's workstations Each of these methods is described in complete 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 (see Figure 2) Lastly, breathing zone (BZ) samples were collected from the paver operator (PO), right screed operator (RSO), and the left screed operator (LSO) In order to establish the control-on vs control-off performance ratio, each sampling position (GA or BZ) was assigned two sampling trains (one for control-on and one for control-off) for each sampling method used The same personal sampling pump was used to pull air through each of the two sampling trains For each day of testing, one sampling train was used during all of the control-on periods, and the other was used during all of the control-off periods In this manner, there was only one IH performance ratio per day established for each of the sampling locations Difficulties encountered with the IH evaluation method included the loss of filters into the asphalt due to the vigorous vibrations and jolting of the paver, long delays between asphalt deliveries affecting sample flow volumes, and the potential for non-paving sources of PACs such as diesel fuel, diesel exhaust, hydraulic fluid, and cigarette smoking to complicate the sample results

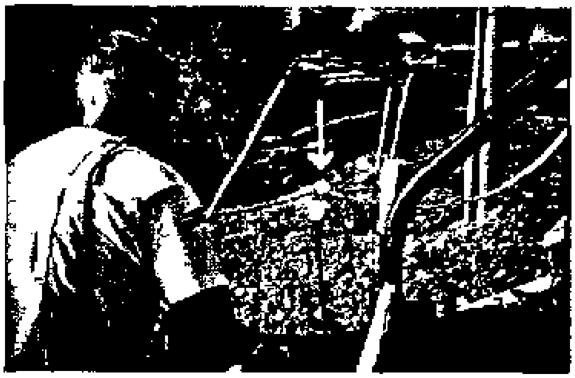

**FIGURE 2.** General-Area (GA) samples using the Total PAC method were placed at each screed operator and paver operator working position

**Real-Time Aerosol Monitoring:** Two types of direct-reading aerosol monitors were used to measure airborne particulate concentrations To reduce the impact of naturally-occurring environmental particulate upon the data results, each of the aerosol monitors was configured to limit recorded measurements to particles with an aerodynamic equivalent diameter of 10 micrometers or less (calibrated to Arizona Red Road Dust) The sampling inlet for one of the particulate monitors, a DataRAM Aerosol Monitor (MIE Inc , Billerica, MA), was positioned in the center of the auger area with the sampling head located 12-15 inches above the top height of the auger blade. In this position, the DataRAM could measure particulate escaping directly from the auger area Sample frequency for the DataRam was set for once every 4 seconds or once every 6 seconds, depending upon the anticipated sampling duration The other two aerosol monitors were Grimm Dust Monitors (Grimm-Labortechnik, Germany) One Grimm was positioned adjacent to one of the paver operator positions while the other was positioned adjacent to a screed operator position The minimum sample frequency option for the Grimms was once every 6 seconds However, the Grimm internally averages the individual readings over a prescribed sample period and reports only the maximum, minimum, and average concentrations for that period For the field paving evaluations, the minium available sample period of 1 minute was selected for these instruments Uncertainties associated with the aerosol monitoring included the unknown effects of varying humidity and instrument vibration The DataRAM sample inlet included an in-line heater which helped to reduce variation due to humidity The Grimms did not have the in-line heater option 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 Inclement weather on the third day of the field evaluation effectively disabled both of the Grimm monitors for the remainder of the evaluation As a result, only two sampling days of data were available for these determinations

**Real-Time Organic Vapor Monitoring:** Real-time total organic vapor monitoring 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 while using the TVAs included the uncertain influence of relative humidity upon the data results (i e humidity changes throughout a pair of long sampling periods could potentially affect the recorded values at low concentrations), instrument drift, and the work practice of using diesel fuel as a cleaning agent and as a release agent to prevent HMA buildup within the paver's feed path These difficulties posed a much greater dilemma as the measured concentrations approached zero Due to its increased sensitivity over the PID, only the FID measurements were used to determine the performance ratio of the engineering control based upon organic vapor measurements collected above the auger The PID measurements were available as a backup, in the event of FID failure Many of the instrument observations collected for the paver and screed operator positions were barely distinguishable from a zero-concentration response This condition occurred during both control-on and control-off conditions Since there was insufficient confidence in the accuracy of these measurements at such low values, no performance ratio for the screed and paver operator positions was established using the TVA data

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

## ENGINEERING CONTROL DESIGN DESCRIPTION

The Blaw-Knox phase two (field) evaluation was conducted on a single prototype engineering control installed on a Blaw-Knox Model PF5510 asphalt paving machine The tested design consisted of two slot-type exhaust hoods (one per side) mounted to the rear of the tractor and above the auger area Each slot was approximately 1-3/4 inches wide and 48 inches long and was positioned above all but the outer 6 inches of each auger A rubber enclosure covered the open area between the two slot hoods and the rear of the tractor, thus helping to minimize escaping fume from the slat conveyor tunnel The two hoods were connected via ducting to a single hydraulic exhaust fan The exhaust fan's stack exhausted the captured air and contaminants approximately 8 feet above the paver deck and approximately 14 feet above the ground The control design was modified for one evaluation period to include additional auger-area enclosure between the rear of the slot hoods and the leading edge of the screed

The Blaw-Knox design offered the option of near-total enclosure, however, when the ends of the screed were extended beyond the edge of the paver to increase the available paving width, the extended portion of the screed had minimal enclosure (see Figure 3) In this position, fumes and vapors within the extended area were virtually non-controlled and fume containment within the auger area was reduced

**FIGURE 3.** Photograph shows right screed gate extended to increase paving width In this position, fumes are uncontrolled and may enter workers' breathing zones

# DATA RESULTS

## Wind Speed and Temperature

The HTA instruments that recorded wind speed and temperature were positioned adjacent to the screed operator and paver operator locations There was no determinable correlation between the measured wind speeds and the exposure concentrations observed by the direct reading instruments The control-off settings yielded average temperatures about 3 3°F higher than the control-on settings and the results were statistically significant at the 20 percent level

## $SF_6$ Determinations

There were a total of six control-on runs in which $SF_6$ determinations could be made Multiple determinations were conducted and averaged within each run, resulting in a total of six average exhaust flow rates and efficiency estimates The average exhaust flow rate was 1630 cfm The average collection efficiency was an 84 percent reduction The lower 95 percent confidence point for the true efficiency was 77 percent Thus, for the $SF_6$ determinations, the true efficiency of the engineering control can be said to be greater than 77 percent with 95 percent confidence The $SF_6$ evaluations were treated as a separate experiment from the environmental monitoring methods Due to its reduced variability, the 95 percent lower confidence limits (LCL) were used as opposed to the 80 percent limits used when evaluating reductions in environmental contaminants

## Environmental Contaminants

Roughly 250,000 data points were statistically evaluated as a result of the 5-day paving evaluation Table I below summarizes the results of the evaluation A more complete description of the evaluation methods may be found in Appendix B

**Table I**
**Engineering Control's Airborne Contaminant Control Efficiencies**

| | Samples above Auger | | | | | Screed/paver Operator Samples | | | |
|---|---|---|---|---|---|---|---|---|---|
| | DataRam (Aerosol) | TVA (Vapor) | IH (Total PACs) | IH (BSF) | IH (Total Part.) | Grimms (Aerosol) | Grimms Upper 25% | IH (Total PACs) | IH Upper 25% |
| Reduction Estimate | 58% | 51% | 55% | 45% | 31% | 54% | 71% | 42% | 62% |
| Individual LCL[1] | 40% | 39% | 43% | 30% | 10% | 48% | 62% | 27% | 52% |
| Simultaneous LCL[2] | 0% | 9% | 16% | 0% | 0% | 36% | 43% | 0% | 33% |

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

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

### Alternate Configuration

There were three full test periods completed on the third full day of sampling. The engineering control configurations for these periods were: (1) control-on with the alternate configuration, (2) control-on with standard configuration, and, (3) control-off. Only the real-time monitoring methods were used during the alternate configuration test period. For this day, the point estimate control efficiencies for the alternate and standard configurations are shown in Table II. Since only one test period in the alternate configuration was evaluated, there were insufficient data with which to develop meaningful confidence limits.

**Table II**
**Control Estimates for Auger Samples, Standard vs Alternate Configurations**

| | DataRam (Aerosol) | TVA (Vapor) | $SF_6$ (Tracer Gas) |
|---|---|---|---|
| Standard | 76% | 87% | 84% |
| Alternate | 90% | 94% | 96% |

# DATA DISCUSSION

The asphalt paving engineering controls project was an experiment that established new ground in the application and performance evaluation of engineering controls. As such, there were no regulatory, consensus, or industry standards by which to evaluate the engineering controls. The hot mobile environment of asphalt paving work and the uncontrollable environmental factors were formidable obstacles. Given these limitations, and in consideration of the time and resource constraints associated with each field evaluation, NIOSH and its partners developed a "shotgun" approach to quantifying engineering control efficiency during asphalt paving. The general concept was to use multiple evaluation techniques in a statistically designed testing strategy of control-off and control-on periods. It was anticipated that some techniques may perform better than others and for that reason, redundant approaches were incorporated into the evaluation protocol. A discussion of each evaluation technique and its usefulness to the Blaw-Knox engineering control evaluation is discussed below.

## Wind Speed and Temperature

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

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

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

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

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

## $SF_6$ Determinations

The result of the $SF_6$ evaluation procedure ($\eta = 84\%$ capture efficiency) is very respectable, although there is a discrepancy between this observation and those of the other auger-area sampling techniques (overall $\eta = 53\%$) There are two possible explanations for the discrepancy (1) The $SF_6$ dosing locations could have been better controlled by the exhaust hoods than other points within the auger area, and, (2) The nature of the $SF_6$ testing protocol minimizes the opportunity for external variables, such as non-auger contaminant sources or extended delays between asphalt deliveries, from interfering with the control quantification process

## Alternate Configuration

Table II clearly shows the benefit of providing some type of additional enclosure to the engineering control design Although the presented data comparisons are limited to point estimates collected on only one day of sampling, the results indicate that the Blaw-Knox engineering control design is capable, through modification, of achieving 90 percent and greater control efficiencies of asphalt fume originating from the auger area

## Environmental Contaminants

### Auger Area--

The results depicted in Table I indicate that the engineering control captured and removed roughly half of the auger-source paving fume There appears to be reasonable consistency between the results for the real-time auger samples (particulate and vapor) and the auger-area IH samples for Total PACs and for Benzene Soluble particulate The moderate discrepancy between the Total Particulate IH samples and the Benzene Soluble Fraction of that particulate potentially reflects non-asphalt sources of particulate such as environmental contamination from adjacent farm fields In addition, fewer useable samples were available for the total particulate analysis due to a limited supply of pre-weighed sample media and the unexpected loss of samples from the rained-out sampling day

### Screed/Paver Operator--

Due to the lower number of samples at the screed and paver operator positions and the potential for increased variability at these distances from the engineering control, all of the industrial hygiene samples (includes GA and BZ Total PAC samples) collected at the non-auger positions were evaluated collectively according to sample type

Since the concentrations observed at the non-auger locations averaged roughly 11-fold lower than those observed immediately above the auger (based upon comparison of IH results), the lower concentrations at the non-auger positions are believed to primarily result from the natural control-effects produced by environmental factors If this assumption is correct, it would help to explain the 13 point difference (55 to 42%) in average control performance based upon the total PAC sampling When the environmental factors are less effective in controlling the auger source emissions, such as during a stagnant wind condition, the worker-area concentrations increase Under these conditions, the contribution of the engineering control becomes increasingly important As a follow-up to this concept, the data were analyzed to determine what contribution the engineering control provided when the environmental factors were not as effective (i e , when work area exposures were at their highest ) For this analysis, the data were analyzed to determine the engineering control's efficiency at reducing the occurrence of the highest 25 percent of 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 67 percent Since, by design, the engineering control only captures fumes originating from the auger area, this analysis also served to verify that the auger area was the major contributing source of higher-level asphalt fume exposures

## CONCLUSIONS AND RECOMMENDATIONS

The scope of this report is the Blaw-Knox phase two (field) evaluation of a prototype engineering control installed on a Blaw-Knox Model PF5510 asphalt paving machine On average, the Blaw-Knox design was successful in capturing and removing 53 percent of the asphalt fume originating from the auger area These performance values represent the achievable level of performance by the evaluated engineering control design under the conditions observed during the Blaw-Knox engineering control evaluation The Blaw-Knox evaluation was only the second of six field evaluations to be conducted as part of the engineering controls research partnership Many of the testing methods had minimal or no history in environments as unique and physically demanding as an asphalt paving environment Knowledge gained during this evaluation resulted in limited changes to the evaluation protocol and potentially impacted the findings of subsequent performance evaluations Many of the environmental and process variables were unique to the Blaw-Knox 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 Blaw-Knox field evaluation completed an important step in this process by successfully demonstrating a 53 percent capture of the auger-source asphalt fume and by reducing workers' exposures by roughly 50 percent Effective July 1, 1997, Blaw-Knox began providing engineering controls as standard equipment on all of their new highway-class pavers As the Blaw-Knox engineering control is adopted into the industry, NIOSH recommends the following (1) Monitor the worker/contractor acceptance of the engineering control design and incorporate changes if undesirable field-modifications are observed, (2) Investigate methods to enhance auger-area enclosure in a manner that is still acceptable to asphalt workers and contractors Based upon the summary results shown in Table II, any increase in enclosure will likely result in an increase in overall capture efficiency, (3) Incorporate protective features that minimize escaping fume when the screed is extended beyond the width of the paver, and, (4) Monitor field conditions of asphalt paver engineering controls to determine how well the control design stands up to the rigorous demands of a paving environment Provide design modifications and maintenance recommendations as necessary to maintain the protective viability of the engineering control

If desired, NIOSH engineers are available to assist in the design or design review of these or other future design considerations

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3 Mickelsen RL, Mead KR [1996] Protocol Evaluation of Engineering Controls for Asphalt Paving U S Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health Report No ECTB 208-07

4 NIOSH [1998] Manual of Analytical Methods, Fourth Edition, Second Supplement U S Department of Health and Human Services (NIOSH) Publication No 98-119, Cincinnati, OH

# APPENDIX A

## ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

## PHASE TWO (FIELD) EVALUATION PROTOCOL

# ASPHALT PAVING FIELD EVALUATION PROCEDURE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

For each Hygro-thermal Anemometers

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

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

For each Foxboro TVA 1000

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

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

DataRAM

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

For each Grimm

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

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

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

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

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

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

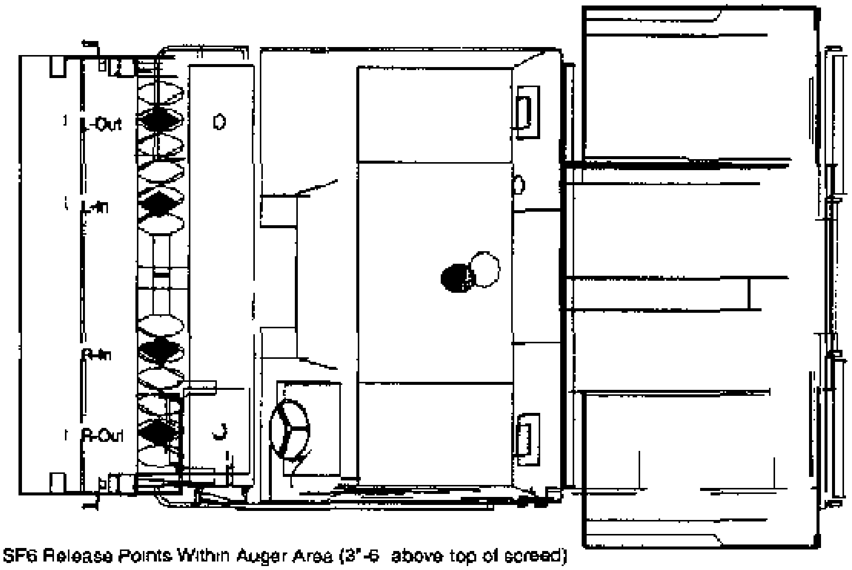
- Calibrate sampling pumps to flow at 2 lpm
- Construct pairs of sampling trains for eight area and three personal sampling positions (total of 22 samples per day)
- Color code each sampling train red=uncontrolled, blue=controlled sampling scenario
- Assign one red and one blue sampling train to each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

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

Additional Measurements

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

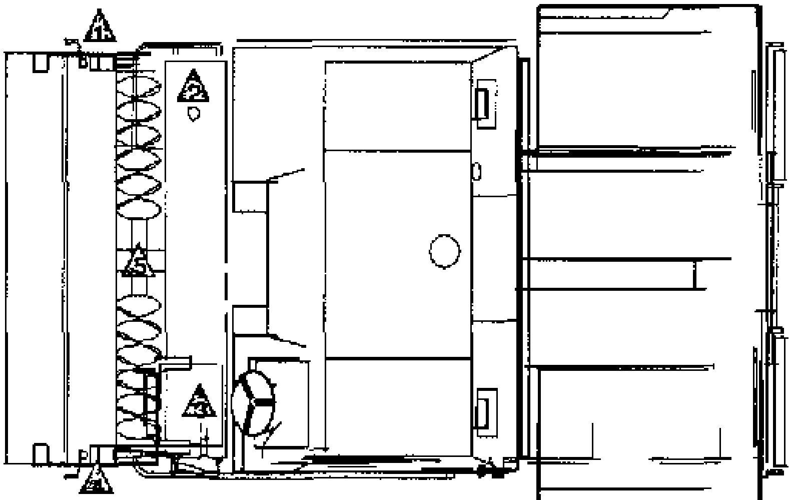
## Figure 1  Tracer Gas Dosing And Sampling Locations



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

● B&K Monitoring Point Within Engineering Control Exhaust Stack

## Figure 2   Real-Time Sampling Locations



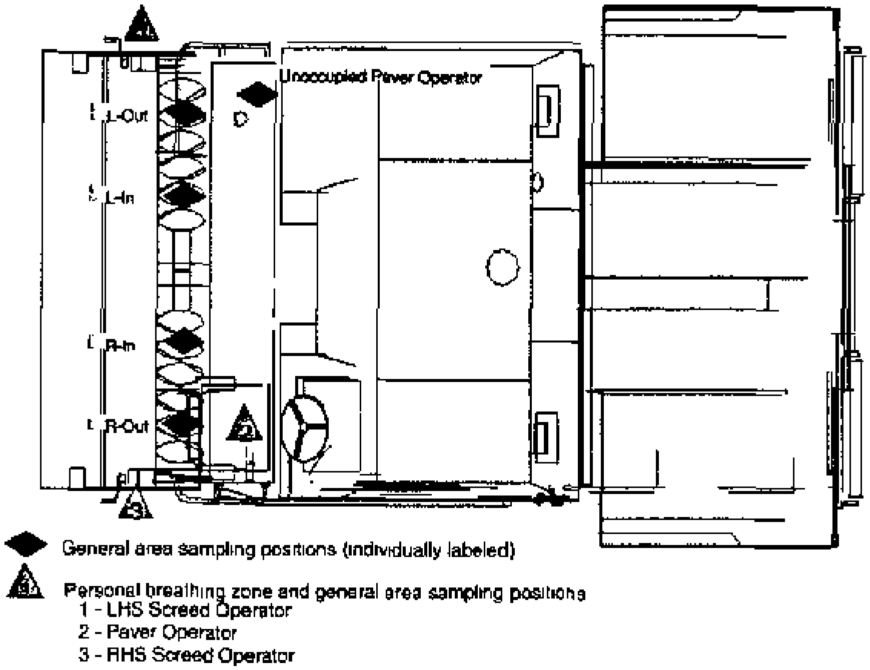
▲ Real Time Sampling Locations

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 |
| Gnmm(x 2) | 1 2 |
| DataRAM | 5 |
| Wind  Temp (x 2) | 1 2 |
| Noise (x 2) | (1,2) (3 4) |
| Heat Stress | (1,2 3 4) |

* Parenthesis denotes rotation among multiple positions

Figure 3 Total-PAC Sampling Locations



# 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

## BLAW-KNOX PHASE TWO FIELD EVALUATION

## STATISTICAL DESIGN AND DATA ANALYSIS

# BLAW-KNOX (MICHIGAN)

## EXPERIMENTAL DESIGN

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

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

**For the real-time samples, averages can be obtained for each control setting shown in Figure 1.** Whereas for the industrial hygiene data, there are no decisions to make about grouping of the data For the real-time samples, there are many decisions to make Since most of these instruments were programmed to make their determinations every 4 seconds, we can use just a portion of the results for a given control setting if we think this approach leads to more precise comparison of control-off with control-on How we chose the portion is discussed in the next section

For purposes of TVA sampling at the screed and operator locations, the periods in the short-time 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 operator or paver operator location, according to the randomization scheme In the long-time periods, the TVA was randomized between screed and operator sampling even though the control setting was unchanged

## METHODS FOR DATA ANALYSIS

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

1 Since these data were collected in batches of control-on and control-off, **it is not appropriate to treat the measurements individually** when making comparison of control and no-control settings The reason is that the variability of measurements made in batches is usually different (smaller) than that of measurements which are collected in a randomized fashion See Figure 2 for real-time particulate data from day 1 of the study 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 far from the center of the distribution, the median is used for the real-time samples (These included vapor and particulate at the auger and away from the auger ) In Figure 2 the median of the control-on measurements is about 176 *micrograms per cubic meter* ($\mu g/m^3$), *compared to about 61* $\mu g/m^3$ *for* the control-off setting

For the industrial hygiene samples, each of which is collected for a relatively long period of time, the average of each type of sample was used, rather than the median Because each sample is a time-weighted average, the sample determinations themselves adjust for extreme values that occur in the course of sampling and the average rather than the median seems appropriate This average was taken over all locations sampled during the control setting The industrial hygiene samples included total PAC at the auger (four locations), 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, there are trends in the real-time data that indicate it may be unwise to use the entire set of data at one control setting.** These trends may be short-time trends or long-time trends Consider Figure 2 again Although there is no apparent trend for the control-off determinations, the control-on determinations seem to decrease during the time period shown These measurements are taken from a larger collection, shown in Figure 3, as the medians of large batches of particulate measurements Each plotted value is a median of over 100 DataRAM determinations Note that the set 2 data shown in Figure 2 are marked in Figure 3, along with two other sets

Comparisons of control-on and control-off depend on the data used to compute the medians The first period of (control-off, control-on) indicates a decreasing trend for the determinations If we compare the median of the entire first period of control-off with that of the entire first period of control-on, we may get quite different results than if we compare the medians shown in set 1 Since we have no control over environmental changes, it makes sense to compare control-on and control-off determinations that are close together in time **In other words, we will compare medians of measurements before and after a change point from one control setting to the other.**

3 Another question concerns **how many measurements to use before and after a change point** Our thinking is that **determinations close together in time are more similar in the uncontrollable variables** We must determine how far in time before and after a control setting change should we include data for computation of the medians Figure 2 (control-on) indicates that as we increase the length of time before the control setting change for inclusion of points The medians used in the comparison can become quite different

We must decide what duration should be taken for each period Comparisons of control effectiveness were done for different length time periods The **number of minutes was always a function of absolute clock time (from the start of the period), since the idea is that it is**

**important to be close together in time to allow for better comparability of the determinations. The periods are constructed with respect to the last measurement before a control setting change or the first measurement after such a change.** For instance, if the last control-off determination before a change occurred at 10 a m , then an hour interval would include measurements between 9 00 and 10 00 a m If the first control-on determination was made at 10 45 a m , then an hour interval would include measurements between 10 45 and 11 45 a m The comparisons indicate that by approximately an hour, the estimated effectiveness of the control is stable and does not change much after that **For the results presented here, hour-long periods are used. Additional explanation is provided in the section of this appendix entitled, "Determining Length of Period."**

4 Trucks were used for delivery of the asphalt for each day **Consequently there were many stops, and in some cases, long delays between truck deliveries.** When there is a long break, environmental differences can affect reduction estimates between the two control settings **Figure 2 also indicates that series occurring after the resumption of paving tend to show increases in particulate levels at the initial start of the series.** This is true for both control-on and control-off settings It is not true for every series, though it is true for the three series shown in Figure 2 It is often true that after a change in control setting and after a stop in paving activity, there is a period of time during which the measurements change their means **Because of this tendency, we have deleted a half minute of real-time measurements before and after a period of no paving.** 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 **For the GRIMM data we use all the data that we can for those measurements which have at least half their minute sampling time in the particular control setting under consideration.**

5 Another issue concerned **drift in the FID and PID determinations** We do not have good zero spanning data for the TVAs for this study The definition of sets used here does not require such data, since the matched data in a set are close together in time, and we would not expect much difference in their drift Also, since vapor measurements away from the auger were close to zero, we regard them as unreliable and do not report them

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 (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 mix to mix differences, pair of (control-on, control-off) within day, and interaction between day and control differences The particulate determinations away from the auger, measured at both the screedman and operator locations, are averaged to obtain one average**

**measurement at each setting at each time, since the two different locations are sampled simultaneously and are correlated.**

**In the analysis of the total PAC data,** the response is the average (on the natural log scale) over the different locations sampled simultaneously for samples of the same type For the total PAC away from the auger, both area and personal samples are included in the average Because the industrial hygiene samples, total PAC or weighing samples, were long-time samples done simultaneously, it was possible to carry out a combined analysis of these data **The control effectiveness was estimated by including all sample types in the same split-plot analysis, and obtaining a separate estimate for each sample type, but pooling the residual variances so as to use a better estimate of the sub-plot variance, with more degrees of freedom** This seemed acceptable, since the bulk of the variability of the measurements is sampling variability, which was thought to be similar, even though the total PAC and the weighing methods are quite different The whole plot error is due to the variability of control setting differences over mixes The sub-plot error is due to variation unexplained after adjustment for sample type and control setting differences

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

8 For many of the comparisons that follow, the aim was **to establish confidence limits that hold simultaneously for all comparisons at the 80 percent confidence level at the auger and at the non-auger locations and also for the IH samples. Thus, for all comparisons simultaneously we can say that the error rate is 20 percent.** The probability that any confidence interval statements are in error is no more than 20 percent **Altogether if eight comparisons were allowed for, then each would be allowed a 2.5 percent error rate. Since the error rates add, the overall error rate will then be 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 vapors produced by the paving process **Alternatively, we could consider each comparison of control-on versus control-off as a separate test In a less ambitious evaluation, only one kind of measurement might be taken. or only one kind of measurement might be of interest. For this consideration, we have also calculated individual 80 percent confidence bands for each determination.** The above approach regarding confidence bands was used for tests of control effectiveness for particulate and vapor **In addition, NIOSH conducted separate investigations whose efficiency confidence limits were calculated independently from the vapor and particulate samples.** These included **tracer gas effectiveness**, for which 95 percent confidence limits were produced, and **evaluation of temperature differences** between control-on and control-off, for which 80 percent confidence bands were calculated

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

## SF6 DETERMINATIONS

The average of the average efficiency by time within day is 83 892 The estimate of this total variance is 67 709, with 5 degrees of freedom The estimated **lower 95 percent confidence limit on the efficiency is 77.128 percent**, obtained as

$$83\ 892-(67\ 609/6)^{0\ 5}\ t_5(\ 95) = 83\ 892 - (11\ 268)^{0\ 5}2\ 015=77\ 128$$

Thus, **at the 95 percent confidence level, it can be said that the true efficiency for the SF6 determinations is at least 77 percent. As was mentioned above, we treat this as a separate experiment and use 95 percent limits here, as opposed to the 80 percent limits used below.** This estimate excludes the cover-on determinations of day 3 When the cover 'on' determinations are included, the overall mean is a little higher (85 68), and the lower confidence limit is 79 17

Positions at which determinations were made were classified as either "inside" or "outside" locations, meaning that the tracer gas was either released towards the center of the auger (inside) or towards the outer edges of the auger (outside) **There is a large difference between the**

**inside and outside determinations** The average reduction estimate for the inside measurements is 88 13 percent, whereas the average reduction estimate for the outside location is 79 65 percent

## EFFECTIVENESS OF CONTROL AT AUGER

The results for the DataRAM and TVA determinations at the **auger** are shown in Figure 4 Results are presented as **percent reduction of the control-on relative to the control-off.** The percent reduction is given separately by day and by average over all days, for the two kinds of samples The average percent reduction is computed by taking the log of the (1-individual period reductions) within each day, averaging these, exponentiating, and subtracting the average from 1

The percent reduction varied considerably over days both for vapor and particulate **For all days, the percent reduction based on DataRAM (particulate) data was about 58 percent. The lower (simultaneous) 80 percent confidence limit was less than 0, and the lower confidence interval constructed for an individual comparison was 40 percent. For the vapor there was estimated reduction of about 51 percent with the 80 percent (simultaneous) lower confidence limit of about 9 percent and lower individual confidence limit of about 39 percent.**

## EFFECTIVENESS OF CONTROL AT OPERATOR AND SCREED POSITIONS

The percent reduction results for the particulate measurements at the screed and operator locations are plotted, by day, in Figure 5, together with the particulate determinations at the auger already shown in Figure 4 **The average reduction based on the non-auger particulate data was about 54 percent with a lower simultaneous confidence interval of about 36 percent and a lower confidence interval for individual comparisons of about 48 percent. Thus, reduction away from the auger is similar to reduction at the auger.**

An alternative approach was attempted to study the **effectiveness of the reduction in particulate at the highest 25 percent of control-off measurements of particulate away from the auger** When the medians of these measurements are compared with the medians of the control-on measurements in the same matched set, somewhat bigger reductions are seen -- **estimated reduction of about 71 percent (Figure 6). The lower confidence limit for simultaneous comparisons is about 43 percent, and that for individual comparisons is about 62 percent. (See Figure 5.)** Since the size 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.** When the control effectiveness is estimated for the upper 50 percent, the reduction is 52 percent, about the same as that based on using all the measurements The observation of higher reduction at higher control-off median appears to be true here, but the limited number of measurements makes the observation applicable to just the upper 25 percent

Differences in percent reduction for the vapor measurements are difficult to express This is primarily due to the very low levels found The median values for each control setting were less than 1 5 ppm, making many of the readings difficult to discern ambient background levels

Figure 7 plots the geometric means for the particulate analyses on the log scale **Some of the GRIMM (particulate) data were high compared to the DataRAM(particulate) auger data** These are two different kinds of instruments, and one would not necessarily expect GRIMM means to be less than DataRAM means The GRIMM data are somewhat different from all the other data collected As was mentioned above, they were 1-minute averages of determinations made every 6 seconds There was no way to examine the ten determinations that went into each of these averages

## IH SAMPLES

Figure 8 is a plot of the percent reduction due to the control, based on the total PAC industrial hygiene sample data (the sum of the 370nm and 400nm wavelengths) and gravimetric samples (total particulate and benzene soluble fraction of the total particulate) The gravimetric samples were all taken at the auger, and there was also total PAC sampling collected at the auger Additional total PAC samples were collected at the screedman and paver operator breathing ones (BZ) as well as the general areas (GA) corresponding to the workers' breathing zones Two or three pairs of BZ samples and four GA samples were collected on each of the four test days However, two of the GA samples are not included in the data due to problems with the sampling equipment

**The total PAC auger samples yield an estimate of about 55 percent reduction due to the control, with lower confidence limit of about 16 percent for simultaneous comparisons and about 43 percent for individual comparisons. The estimate for the combined total PAC non-auger area samples and breathing zone samples was about 42 percent with a lower confidence limit indicating no reduction for simultaneous and about 27 percent for individual comparisons. The benzene soluble samples and total particulate samples yielded reductions of 45 and 31 percent, respectively. Although the lower confidence limits for both indicate no statistically significant reduction for simultaneous comparisons, the lower confidence limits for individual comparisons were respectively, 30 and 10.2 percent.** Only two days of samples were available for the total particulate samples

Just as for the particulate data away from the auger, an alternative approach was attempted to study the **effectiveness of the reduction in total PACs at the highest 25 percent of control-off measurements away from the auger (Figure 9)** When these highest measurements are compared with the control-on measurements in the matched pair at the same sampling location on the same day, bigger reductions are seen -- **estimated reduction of about 62 percent and**

**lower confidence limit on the reduction of about 33 percent for simultaneous comparisons and about 52 percent for individual comparisons.**

The selection of the 25 percent cutoff is somewhat arbitrary For instance, if the effectiveness of the control is evaluated for the upper 50 percent, then the results are similar -- estimated reduction of about 58 percent due to the control, with (simultaneous) lower confidence limits of about 30 percent These data suggest that **if the control-off value is sufficiently high, then the control effectiveness will also be high.** One interpretation is that when the environmental factors do not significantly contribute to the control of the analytes, then the control-off measurements will be greater and the potential contribution by the engineering control increases **Figure 9 is interesting because it also suggests that the control is often effective when the control-off values are low but for such situations the results are more variable.** The five low values are from three different days of sampling and include two BZ samples and three GA samples

Figure 10 gives the daily geometric means of the total PAC BZ and non-auger GA by type (BZ/GA) and by control setting (on/off) **Except for the first day of sampling, the breathing zone samples have smaller overall averages and smaller estimated reductions than the area samples.** However, each estimated reduction is based on only a few samples and the BZ samples, which were mounted on the workers, sometimes left the general vicinity of the asphalt paver

Figure 11 shows the relationship between benzene soluble determinations and total PAC determinations at the auger A relationship can be developed because there were filter samples (for modified OSHA method analysis) paired with the total PAC samples at the auger **The approximate straight line relationship is useful if it explains most of the variation. For these data, a single line explains less than half of the variability, and somewhat different trend lines appear for each day. The data from the last day of sampling is not linear. From these data, prediction of benzene soluble determinations from total PAC does not seem very precise.**

The IH data do allow us to make another estimate of the efficiency of the control for vapors The filters that were used for gravimetric analyses had tube backups These tubes collected only vapor, since the particulate was extracted by the filters Thus, the efficiency of the control can be estimated by both the backup tube data (vapors) and the filter data (particulate) (It is unknown to what extent off-gassing from the captured particulate may contribute to the vapor concentration ) The accompanying Figure 12 displays the efficiency by sampling day **There is no evidence that the vapor estimates based on the tube data differ in any consistent way from those based on the filter data.**

## WIND AND TEMPERATURE MEASUREMENTS

The HTA instruments were located at the screedman and operator locations As in the other comparisons, median temperatures were used for this comparison, based on the pairing scheme described above However, medians were calculated for the first 5 minutes after a control setting change or for the last 5 minutes before such a change, since any temperature effects should happen quickly **The control-off settings yielded average temperatures about 3.3 degrees F higher than the control-on settings. The results are statistically significant at the 20 percent significance level.**

Median wind speeds were calculated for each control setting used in the randomization These determinations and the temperature determinations were made by two HTA instruments, located near the GRIMMs at either the screed positions or the operator positions **There is no clear relation between wind speed and amount of particulate or vapor.**

## CONCLUSIONS

| | Part - auger Real-time | Vapor-auger Real-time | Total PAC-auger Indus Hygiene | Benz Sol - Auger | Total Part - Auger | Part - non auger Real-time | Part-non-auger upper 25% | Total PAC non-auger Indus Hygiene | Total PAC non auger-upper 25% |
|---|---|---|---|---|---|---|---|---|---|
| Est | 58% | 51% | 55% | 45% | 31% | 54% | 71% | 42% | 62% |
| Simult LCL | 0% | 9% | 16% | 0% | 0% | 36% | 43% | 0% | 33% |
| Indiv LCL | 40% | 39% | 43% | 30% | 10% | 48% | 62% | 27% | 52% |

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

## STATISTICAL SECTION - DETERMINING LENGTH OF PERIOD

The data in this study were collected in periods of several hours at each control setting This was true for both real-time and industrial hygiene samples **Whereas for the industrial hygiene samples, we must use the measurement of each sample, for the real-time samples we can**

**choose which samples we might use. Why choose? The reason is that we believe 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 15, 30, 37.5, 45, and 60 minutes after a control setting change and before a control setting change. The estimates of control effectiveness are given for the auger measurements, both particulate and vapor. These are given as **average [ln(control-off)-ln(control-on)], plus the standard error.**

| | | | Data RAM | |
|---|---|---|---|---|
| | FID Estimate | Standard Error | Estimate | Standard Error |
| 15 min results | 0.032 | 0.40 | 0.13 | 0.41 |
| 30 min results | 0.37 | 0.49 | 0.46 | 0.36 |
| 45 min results | 0.59 | 0.33 | 0.73 | 0.39 |
| 60 min results | 0.72 | 0.23 | 0.87 | 0.39 |
| 120 min results | 0.47 | 0.23 | 1.00 | 0.59 |

To obtain these estimates, **some paving sequences close to a time of changed control setting were deleted.** These are **sequences which have long breaks, say more than 15 minutes, before the next sequence. Also on the second day of sampling all measurements between the hours 12.601 and 13.190 were deleted because of a rising trend in determinations that started in control-off and continued in control-on. This trend seemed to indicate an outside FID contaminant, not related to the paving activities at the auger.**

**In the above table, for the FID, the greatest difference [ln(control-off)-ln(control-on)] is at 45 and 60 minutes - between 0.59 and 0.72 (which correspond respectively to 45 and 51 percent reduction due to the control). The standard errors are smaller for the longer durations. For the DataRAM there is a tendency for reduction estimates to improve as the period length increases.** On the other hand, **the period length is nominal, since there are gaps in the data.** Although it is clear that the DataRAM data do vary with time length, it **seems sensible to try to infer that changes take place relatively quickly.** It makes some sense to use the 60 minute results for both FID and DataRAM and for the GRIMMS, too. **For the DataRAM the estimated difference [ln(control-off)-ln(control-on)] is 0.87 (or 58 percent reduction due to the control) for 60 minute results and 1.00 (or 63 percent reduction due to the control) for 120 minute results. Both have lower simultaneous confidence limits less than 0. The individual lower confidence limits on reduction are 40 percent for the 60 minute data and**

**43 percent for the 120 minute data. Thus, there is very little difference between the 60 minute results and the 120 minute results. Either time length shows the control effectiveness at its maximum.**

# LIST OF FIGURES

## FIG 1 RANDOMIZATION SEQUENCE

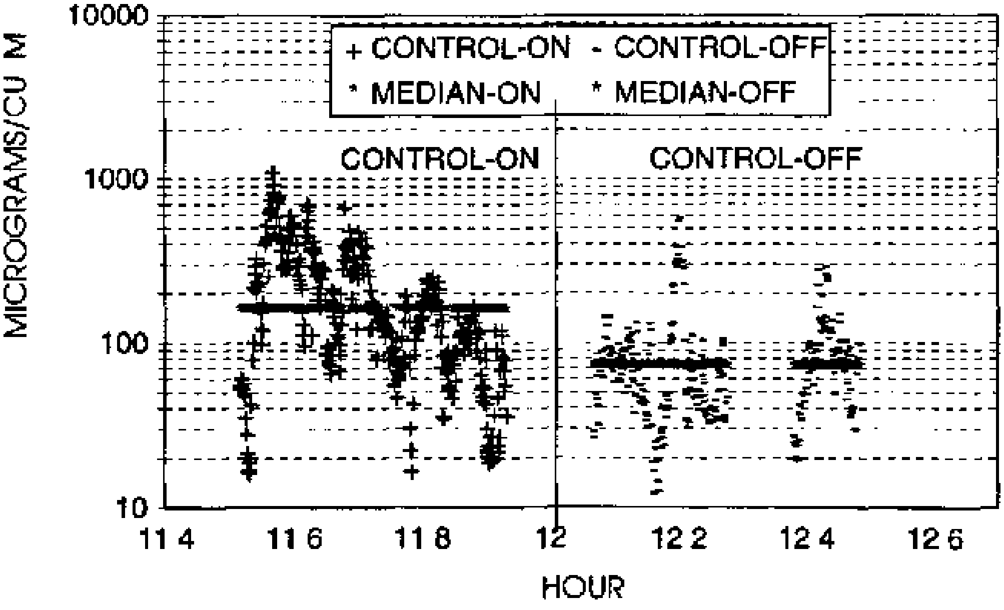
FOUR DAYS OF LONG-TIME PERIODS

| | | | | |
|---|---|---|---|---|
| | DAY 1 | DAY 2 | DAY 3 | DAY 4 |
| PERIOD 1 | L-OFF | L-ON | L-COVER* | L-OFF |
| PERIOD 2 | L-ON | L-OFF | L-ON | L-ON |
| PERIOD 3 | L-OFF | L-ON | L-OFF | L-OFF |
| PERIOD 4 | L-ON | L-OFF | | L-ON |

*L-COVER = LONG-TIME PERIOD, WITH CONTROL-ON PLUS ENCLOSURE,
L-ON INDICATES CONTROL-ON, L-OFF INDICATES CONTROL-OFF

## FIG 2 DAY 1 - SET 2- PARTICULATE DATA AT AUGER

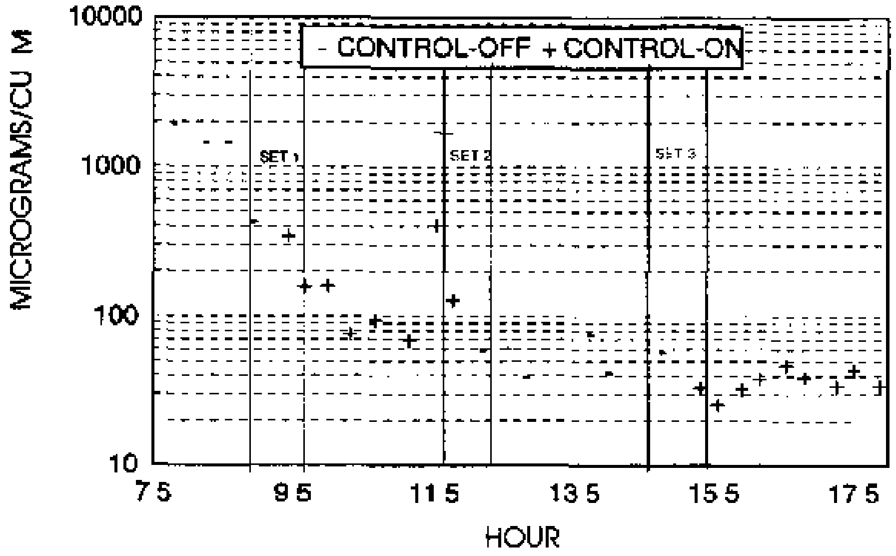
LOG SCALE



TIME SEGMENTS WITHOUT DATA INDICATE NO PAVING WORK BEING DONE NOTE TRENDS IN CONTROL-ON DATA NOTE THAT CONTROL-OFF SERIES THAT SUCCEED NO-WORK SEGMENTS SHOW INCREASE AT START OF SERIES

FIG 3 LOG MEDIANS OF PARTICULATE MEASUREMENTS FOR DAY 1

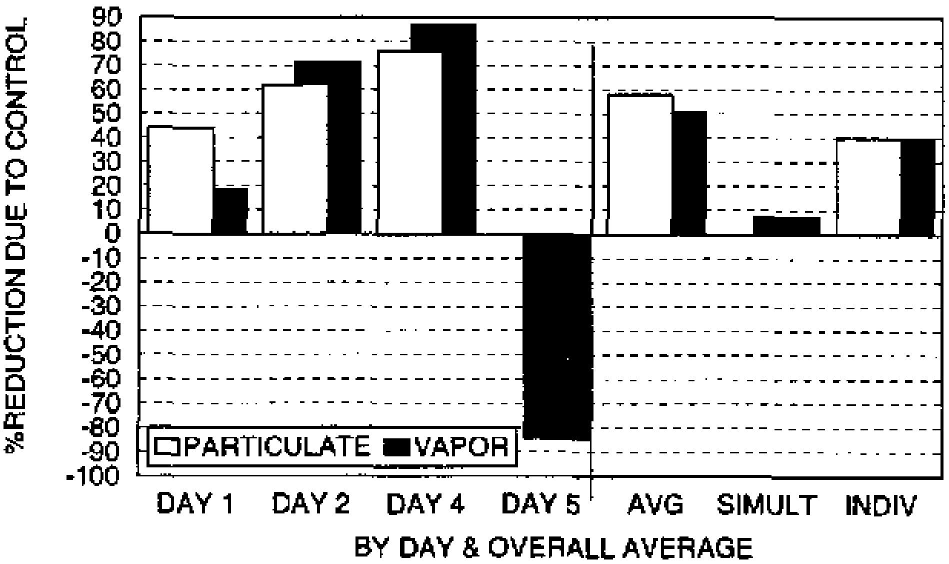
EACH MEDIAN IS BASED ON AT LEAST 100 MEASUREMENTS



CONTROL OFF IS HIGH AT BEGINNING OF DAY COMPARISONS BASED ON MARKED SETS CAN BE DIFFERENT FROM THOSE BASED ON ENTIRE PERIODS OF MEASUREMENTS

FIG. 4: AUGER RESULTS. %REDUCTION BY DAY & OVERALL AVERAGE

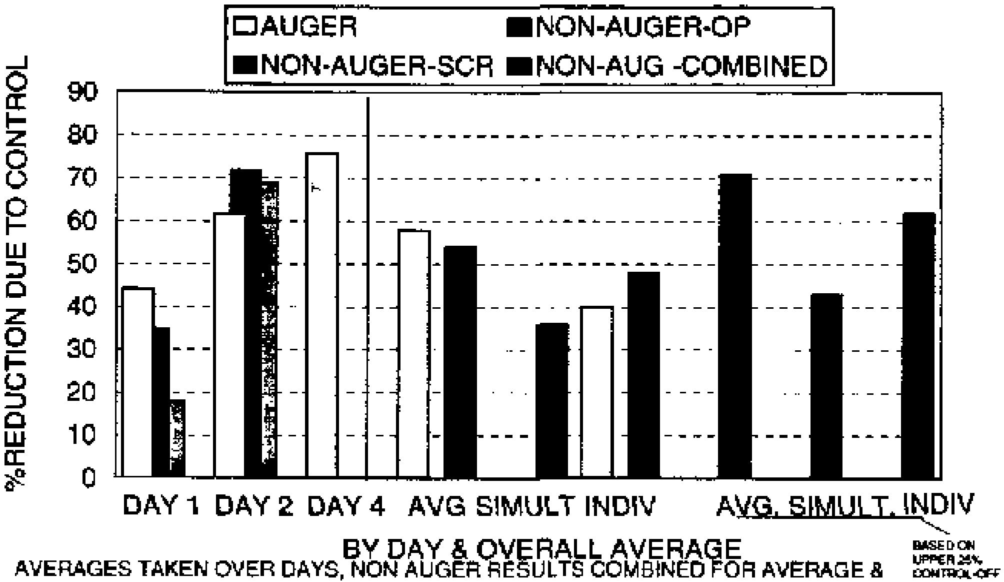
LOWER 80% CONFIDENCE LIMITS SIMULTANEOUS & INDIVIDUAL VAPOR & PARTICULATE



AVERAGES TAKEN OVER DAYS, NO RAM RESULTS ON DAY 5 AVERAGES COMPUTED AS FOLLOWS OBTAIN DAILY LN(CON ON / CON OFF) VALUES EXPONENTIATE AVERAGE OF THESE VALUES & SUBTRACT THIS AVERAGE FROM 1 TO OBTAIN AVERAGE REDUCTION FOR SIMULTANEOUS LIMITS 0 REDUCTION FOR PARTICULATE

## FIG. 5: PARTICULATE: %REDUCTION BY DAY & OVERALL AVERAGE

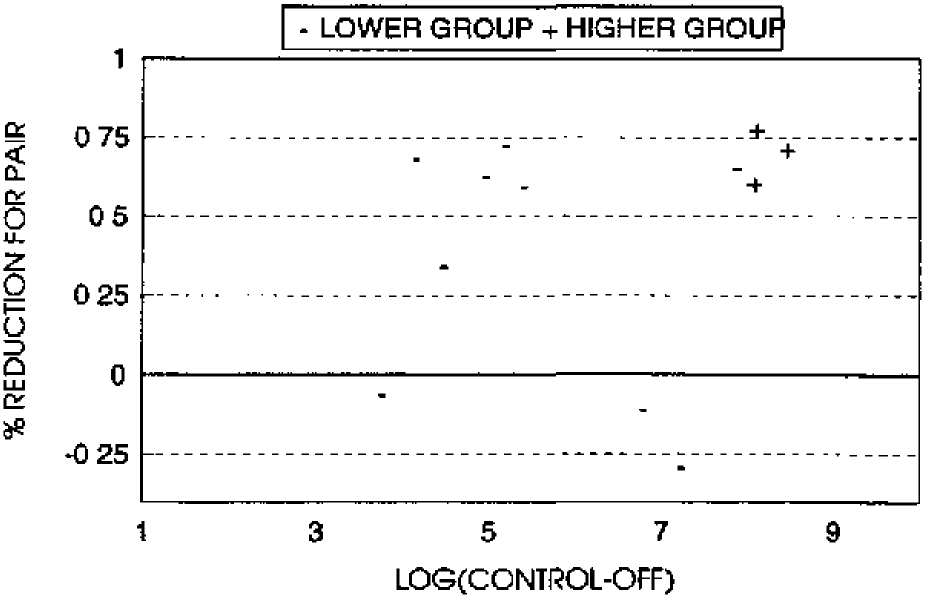
LOWER 80% CONFIDENCE LIMITS, SIMULTANEOUS & INDIVIDUAL



AVERAGES TAKEN OVER DAYS, NON AUGER RESULTS COMBINED FOR AVERAGE & CONFIDENCE LIMITS , NO NON-AUGER RESULTS FOR DAYS 4 & 5 NO AUGER RESULTS FOR DAY 5 SIMULTANEOUS RESULTS ARE ZERO FOR AUGER

## FIG. 6 : % REDUCTION FOR LOWEST 75% CONTROL-OFF VERSUS HIGHEST 25% CONTROL-OFF PAIRS

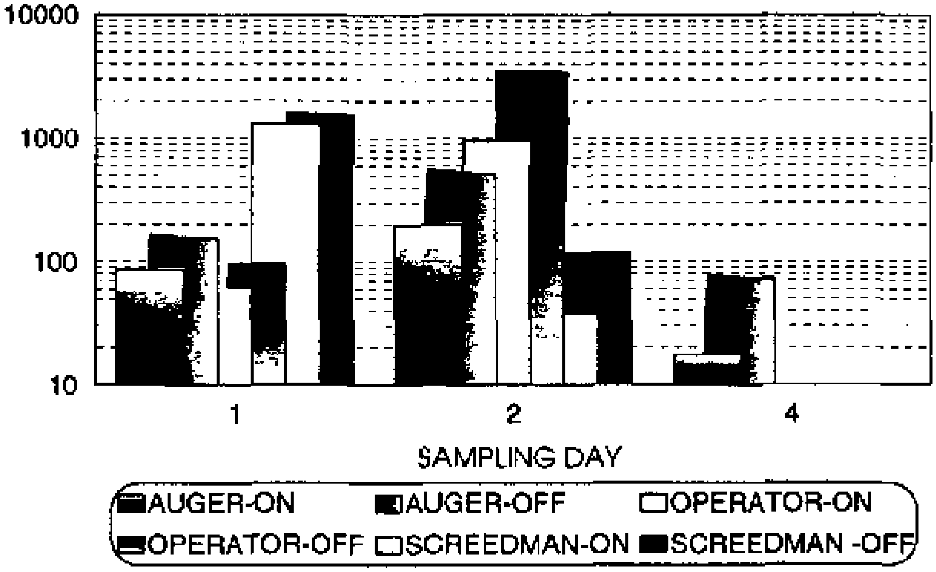
FOR REAL-TIME PARTICULATE SAMPLES AWAY FROM AUGER



HIGHER GROUP HAS LARGER REDUCTION

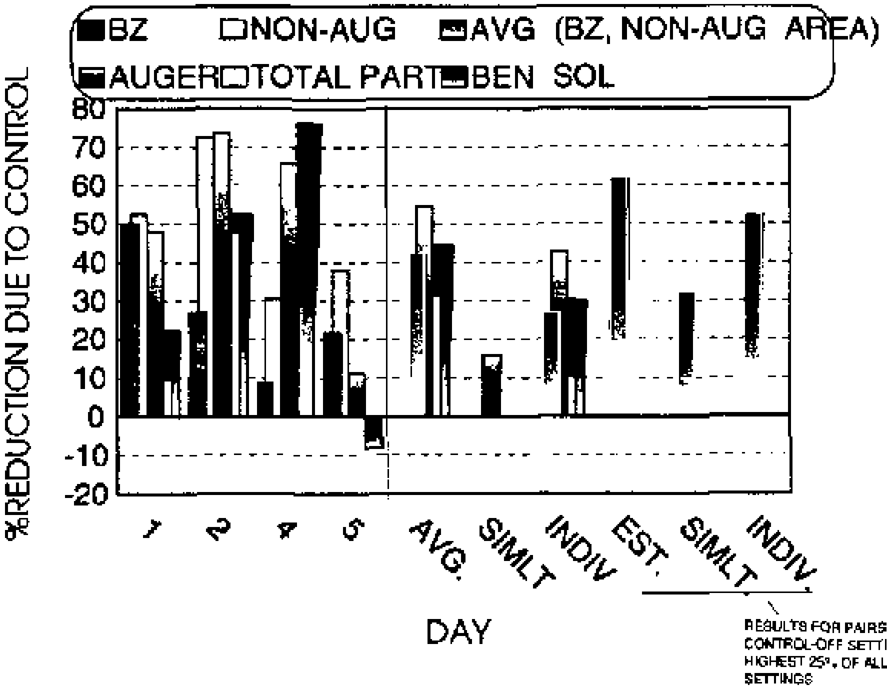
## FIG 7: REAL-TIME PARTICULATE GEOMETRIC MEANS-LOG SCALE

AUGER MEASUREMENTS VIA RAM, NON-AUGER VIA GRIMMS



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

TOTAL PACs, TOTAL PARTICULATE, AND BENZENE SOLUBLES

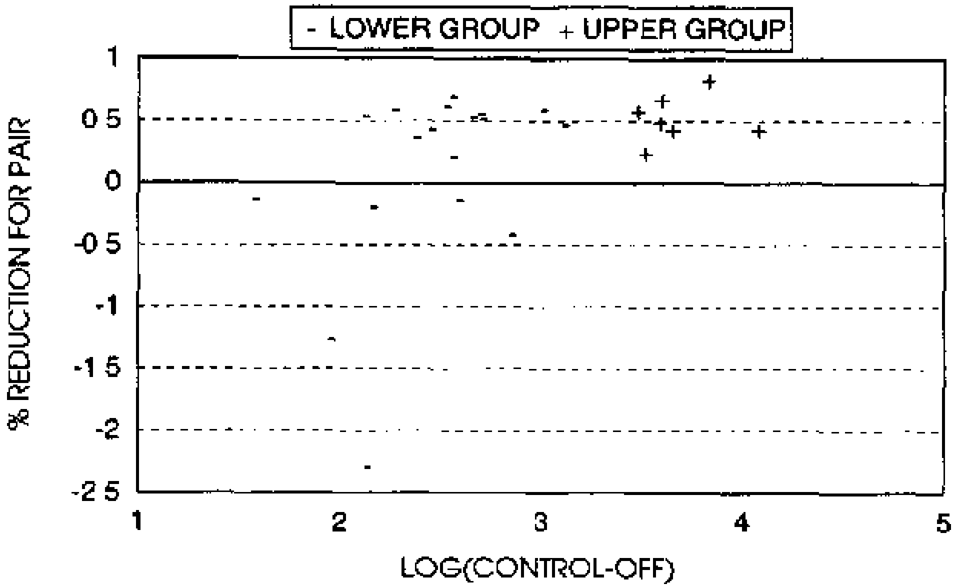


RESULTS FOR PAIRS FOR WHICH CONTROL-OFF SETTING IS IN HIGHEST 25%, OF ALL CONTROL-OFF SETTINGS

FOR TOTAL PACS , %REDUCTIONS BASED ON GEOMETRIC MEANS OF SUMMED 370nm AND 400nm DETERMINATIONS BREATHING ZONE AND NON-AUGER AREA SAMPLES COMBINED FOR CONFIDEN LIMITS

## FIG 9 % REDUCTION FOR LOWEST 75% CONTROL-OFF VERSUS HIGHEST 25% CONTROL-OFF PAIRS

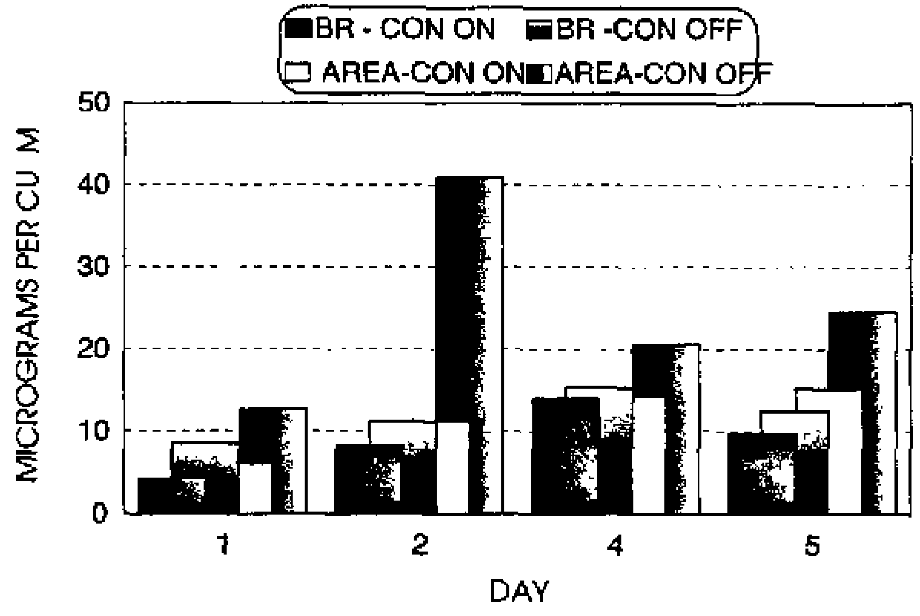
FOR TOTAL PAC AREA & BREATHING ZONE SAMPLES AWAY FROM AUGER



HIGHER GROUP HAS LARGER REDUCTION

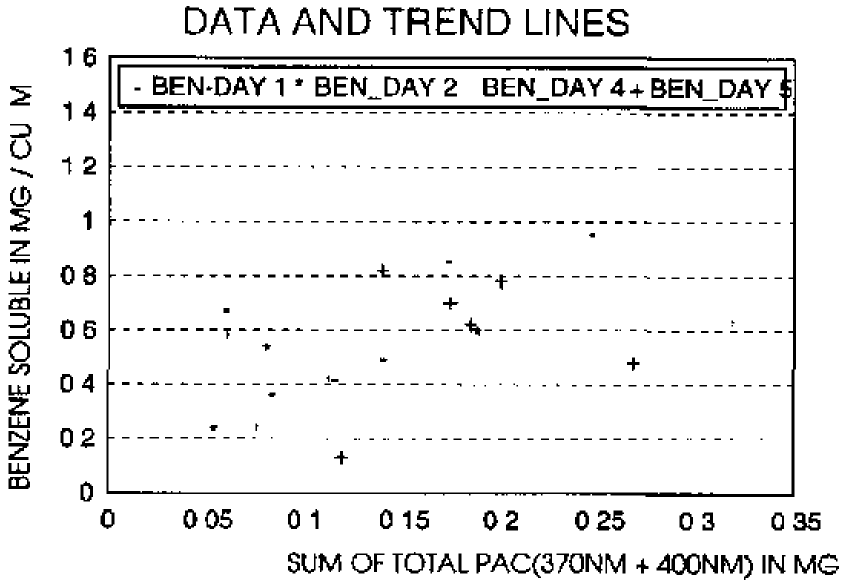
## FIG. 10: INDUSTRIAL HYGIENE SAMPLES. GEOMETRIC MEANS

TOTAL PACs FOR BREATHING ZONE & NON-AUGER AREA SAMPLE



%REDUCTIONS BASED ON GEOMETRIC MEANS OF SUMMED 370nm AND 400nm DETERMINATIONS
NON-AUGER AREA CONTROL-OFF SAMPLE ON DAY 2 BASED ON JUST TWO LOCATIONS

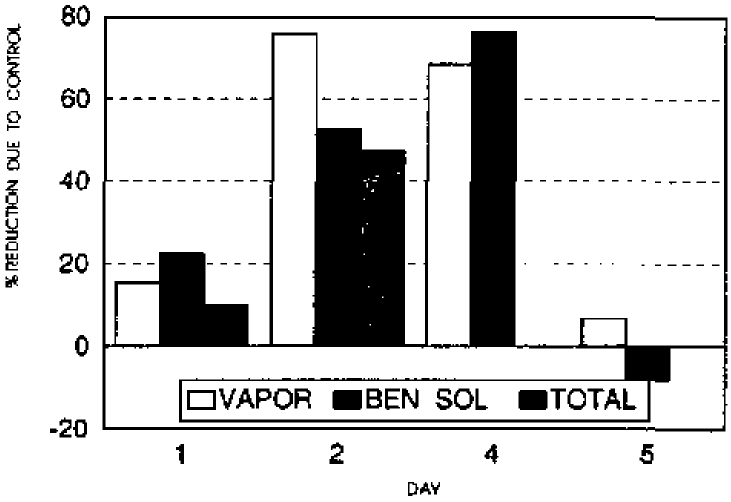
FIG. 11 AUGER BENZENE SOLUBLE VS SUM OF INSTRUMENTAL RESPC
(370NM + 400NM)



EXCEPT FOR DAY 5 DATA, THERE IS CONSIDERABLE LINEARITY TO EACI
DAY'S DATA THERE IS A LOT OF SCATTER ABOUT EACH TREND LINE

FIG 12 REDUCTION DUE TO CONTROL AT AUGER

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



DAYS 2 & 3 VERY DIFFERENT FROM DAYS 1 & 5 TOTAL PARTICULATE SAMPLES MISSING FOR DAYS 4 & 5 NO EVIDENCE THAT VAPOR SAMPLES DIFFER CONSISTENTLY FROM NON VAPOR SAMPLES