PB2000-105171

IN-DEPTH SURVEY REPORT:

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

MANUFACTURER: Roadtec Paving Products

PAVING CONTRACTOR: C.W. Matthews Contracting Company

PAVING LOCATION: Calhoun, Georgia

REPORT WRITTEN BY:
Kenneth R. Mead
Ronald L. Mickelsen
Stanley A. Shulman

REPORT DATE:
March 2000

REPORT NO.:
ECTB 208-22a

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Division of Applied Research and Technology
Engineering and Physical Hazards Branch
4676 Columbia Parkway, R5
Cincinnati, Ohio 45226

REPRODUCED BY: NTIS
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

PLANT SURVEYED:	Roadtec Paving Products (Paver Manufacturer) C.W. Matthews Contracting Company (Paving Contractor), Calhoun, Georgia
SIC CODE:	1611
SURVEY DATE:	November 4-7, 1996
SURVEY CONDUCTED BY:	Kenneth R. Mead Ronald L. Mickelsen Daniel Farwick Stanley A. Shulman Greg Kinnes Jeff Bryant James McGlothlin
EMPLOYER REPRESENTATIVES:	Roadtec, Dave Swearingen Chief Engineer C.W. Matthews, Tommy Brewster Area Superintendent
EMPLOYEE REPRESENTATIVES:	None
MANUSCRIPT PREPARED BY:	Bernice L. Clark Frankie J. Smith, Editorial Assistant

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EXECUTIVE SUMMARY

On November 4-7, 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 Roadtec engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment. NIOSH researchers conducted the research through an inter-agency agreement with DOT's Federal Highway Administration (FHWA). Industry, labor, and governmental participation in the project was fostered through a research partnership which included NIOSH, FHWA, the National Asphalt Pavement Association (NAPA), the Asphalt Institute, six manufacturers of asphalt paving equipment, the International Union of Operating Engineers (IUOE), the Laborers' International Union of North America (LIUNA), and the Laborers' Health and Safety Fund of North America (LHSFNA).

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

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

The scope of this report is limited to the Roadtec phase two (field) evaluation of a single engineering control installed on a Roadtec Model RP 180-10 asphalt paving machine. The tested design consisted of twin exhaust hoods mounted above the auger area, one on each side of the auger gear box. Each hood incorporated flanges on the leading and trailing edges of the hood, to enclose approximately 70 percent of the top of the auger area. Airborne contaminants were exhausted from the auger area through the use of two hydraulic exhaust fans. Each fan exhausted via a plenum and flexible ducting system to collect asphalt fumes from three pick-up points along its respective side of the auger. The discharge from the two

fans combined into a single exhaust stream and exited through an exhaust stack located on the paver deck. The stack discharge point was approximately 6 feet above the paver deck and about 12 feet above the ground.

Field tracer gas measurement techniques revealed an average exhaust flow of 1940 cubic feet per minute (cfm) from the exhaust fan. Test results indicate that the Roadtec engineering control design was successful in capturing and removing an average of 79 percent of the asphalt fume released from the auger area. This source reduction led to an average worker-area reduction of 45 percent. Another metric of interest is the engineering control's influence upon exposure reductions when the uncontrolled exposures are at their highest levels (top 25 percent). Using this approach, the Roadtec engineering control produced an average reduction in higher-level work area exposures of 54 percent.

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

The implementation of engineering controls on asphalt paving equipment will continue to be an iterative process. NIOSH encourages Roadtec to incorporate the following recommendations into their engineering control implementation process: (1) Monitor the worker/contractor acceptance of current/future auger-area enclosure designs and incorporate design changes if undesirable field-modifications are observed; (2) Monitor field conditions of asphalt paver engineering controls to determine how well the control design weathers the rigorous demands of a paving environment; (3) Modify or supplement the existing hood enclosure to minimize escaping fume when the screed is extended beyond the width of the paver; and, (4) Consider developing a control approach to minimize fume exposures originating from the material transfer of HMA into the receiving hopper.

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 November 4-7, 1996, researchers from NIOSH evaluated a first-generation engineering control designed to capture and remove fugitive asphalt emissions during asphalt paving. The Roadtec engineering control evaluation was completed as part of a Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment. NIOSH researchers conducted the research through an inter-agency agreement with DOT's Federal Highway Administration (FHWA). Industry, labor, and governmental participation in the project was fostered through a research partnership which included NIOSH, FHWA, the National Asphalt Pavement Association (NAPA), the Asphalt Institute, six manufacturers of asphalt paving equipment (Barber-Greene/Caterpillar, Blaw-Knox, Cedarapids, Champion, Dynapac, Roadtec), the International Union of Operating Engineers (IUOE), the Laborers' International Union of North America (LIUNA), and the Laborers' Health and Safety Fund of North America (LHSFNA).

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

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

The Roadtec phase one evaluation occurred in June 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 Roadtec Incorporated, Chattanooga, Tennessee."[2] Since the phase one evaluation was only one portion of the overall development and evaluation of the Roadtec engineering control, finalization of the Roadtec phase one report was delayed until the completion and co-release of Roadtec's phase two report.

The scope of this document is the Roadtec phase two (field) evaluation of a prototype engineering control installed on a Roadtec Model RP 180-10 asphalt paving machine (see Figure 1). Participating NIOSH researchers included Ken Mead, Mechanical Engineer; Leroy Mickelsen, Chemical Engineer; Dan Farwick, Industrial Hygiene Technician; Stan Shulman, Statistician; and Jim McGlothlin, Industrial Hygiene Engineer, all from DART, Greg Kinnes, Industrial Hygienist from the Division of Surveillance, Hazard Evaluation, and Field Studies (DSHEFS); and Jeff Bryant, Industrial Hygienist from the Education and Information Division (EID). The NIOSH team was augmented by Tom Brumagin, NAPA's Director of Environmental Services and Dave Swearingen, Chief Engineer at Roadtec. The field evaluation was conducted in coordination with Georgia paving contractor, C.W. Matthews Contracting Company at a highway paving project on Interstate 75, near Calhoun, Georgia. Tommy Brewster, Area Superintendent, represented C.W. Matthews.

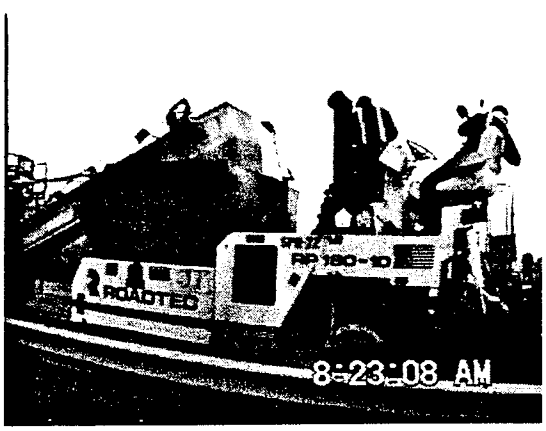

Figure 1. Roadtec Model RP 180-10 Asphalt Paving Machine undergoing field testing of prototype engineering controls. The testing site included both day and night paving operations on Interstate 75 near Calhoun, Georgia.

EVALUATION PROCEDURE AND EQUIPMENT

With the input of its partners, NIOSH researchers developed an evaluation protocol that focused on each engineering control's ability to capture and remove airborne contaminates generated within the asphalt paver's auger area.[3] Secondary measurements were collected at screed and paver operator positions located on the asphalt paver. The primary focus was the control of asphalt fume, a particulate with a diameter of about 1.0 micrometer (1×10^{-6} meters) and smaller. A secondary focus was on the control of organic vapors originating from the hot mix asphalt (HMA). Since no prescribed methods existed to evaluate engineering controls under the unique physical constraints of the asphalt paving environment, a multifaceted protocol using multiple evaluation methods was developed to quantify each engineering control's performance (Appendix A). Each of the evaluation methods within the protocol has inherent advantages and disadvantages, some of which can have an effect on the calculated results. An additional advantage of using multiple evaluation methods was that at times, the harsh environment led to equipment malfunctions and the loss of important data. In the case of the Roadtec evaluation, the double-shift work duration exceeded the battery limitations of some equipment. The impact of these data losses was lessened by the presence of multiple evaluation tools. It was anticipated that some of these methods would work better than others and that as the overall project progressed, adjustments would be made to the selection and application of the evaluation methods based upon prior experiences. A listing and description of the evaluation methods follow.

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 SF_6 dosing technique for determination of SF_6 capture efficiency required modification for use during 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 auger's center shaft. In this manner, the SF_6 was injected in uniform amounts across the four dosing points, into the flow of fume and vapors convectively rising out of the auger head space. For the Roadtec evaluation, the total dosing flow of SF_6 was approximately 0.8 liters per minute (lpm) [0.2 lpm per needle]. Multiple tests were conducted during the control-on test periods. Difficulties encountered with the field tracer gas method included maintaining the injection needles at the prescribed locations, preventing needle obstruction due to occasional contact with the HMA, and maintaining a steady supply of 120V electrical current to the dosing and sampling equipment.

Industrial Hygiene Sampling: Industrial hygiene (IH) sampling trains were configured for use with two analytical sampling methods. The first method quantified the total particulate drawn into a filter cassette and then determined what portion of the collected particulate was soluble in benzene. This latter part of this method is often referred to as the Benzene Soluble Fraction (BSF) method. Due to anticipated detection limitations, this method was only used at sampling locations directly above the auger. The second IH sampling method was a new analytical method developed by NIOSH research chemists. The new method quantified concentrations of total polycyclic aromatic compounds (PACs) and was reportedly more sensitive than the asphalt fume sampling method previously described. Due to the increase in sensitivity, the total PAC method was used for sampling both above the auger and at each of the asphalt paver's workstations. Each of these methods is described in detail in the NIOSH Manual of Analytical Methods (NMAM).[4]

At the auger area, four general area (GA) sampling locations were uniformly distributed across the width of the auger. Additional GA sampling locations included the right and left paver operator positions and the right and left screed operator positions. Lastly, breathing zone (BZ) samples were collected from the paver operator (PO), right screed operator (RSO), and the left screed operator (LSO). In order to establish the control-on vs. control-off performance ratio, each sampling position (GA or BZ) was assigned two sampling trains (one for control-on and one for control-off) for each sampling method used. The same personal sampling pump was used to pull air through each of the two sampling trains. During previous field evaluations, one sampling train was used during all of the control-on periods and the other was used during all of the control-off periods during each day of testing. In that manner, there was only one IH performance ratio per day established for each of the sampling locations. However, based upon prior experience and the reduced prospects for sampling opportunities (HMA plant failure canceled paving on day 1), a double set of IH samples was collected during the extended paving period from November 6-7, 1996. Difficulties encountered with the IH evaluation methods included: (1) Limited sampling opportunities; (2) Area contamination from non-paving sources of PACs such as diesel fuel used as a solvent (see Figure 2), potential propane contamination from a portable torch used to heat the

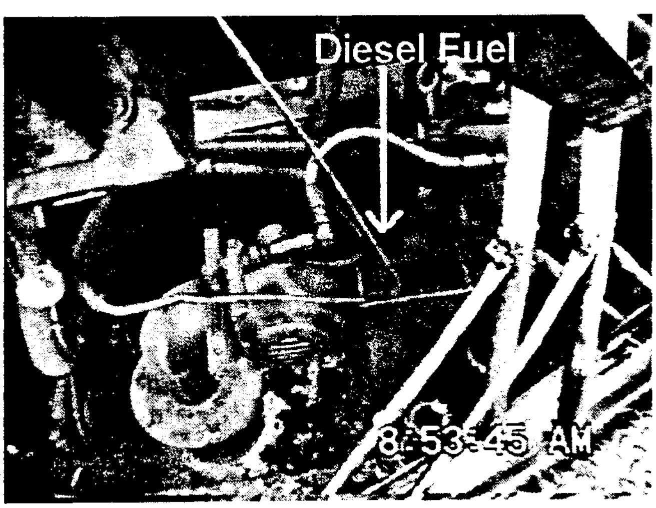

Figure 2. Photograph showing open container of diesel fuel, heated to a boil, while placed on top of the screed heater. Non-paving sources of aromatic compounds such as diesel fuel may have adversely affected the measured exposure reductions at paver workstations.

ski plates and cigarette smoking; and, (3) Non-auger sources of asphalt fume associated with the material transfer vehicle (Shuttle Buggy) or the freshly paved surface.

Real-Time Aerosol Monitoring: Two types of direct-reading aerosol monitors were used to measure airborne particulate concentrations. 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), thus ignoring the majority of ambient airborne particulate. The sampling inlet for one of the particulate monitors, a DataRAM Aerosol Monitor (MIE Inc., Billerica, MA), was positioned in the center of the auger area with the sampling head located about 12 inches above the top of the auger blade. In this position, the DataRAM could measure particulate escaping directly from the auger area. Sample frequency for the DataRAM was once every 4 seconds. The other two aerosol monitors were Grimm Dust Monitors (Grimm-Labortechnik, Germany). One Grimm was positioned adjacent to one of the paver operator positions while the other was positioned adjacent to a screed operator position. The minimum sample frequency option for the Grimms was once every 6 seconds. However, the Grimm internally averages the individual readings over a prescribed sample period and logs only the maximum, minimum, and average concentrations for that period. For the field paving evaluations, the minimum available logging period of 1-minute was selected for these instruments. Difficulties associated with the aerosol monitoring included equipment failure due to loss of battery power (the Grimms did not have the capacity to sample throughout the double-shift paving period.) and the unknown effects of varying humidity and instrument vibration. The DataRAM sample inlet included an in-line heater which reduced variation due to humidity. The Grimms did not have the in-line heater option; however, the modified testing protocol incorporated multiple pairs of short-term (5-10 minutes per control setting) sampling. Under the modified protocol, sampling effects due to varying humidity are expected to be negligible. Vibration isolators were used with all of the aerosol monitors in an effort to minimize vibrational error. Both types of aerosol monitors included an internal warning feature for excessive vibration; however, it is unknown how much error can occur before these warnings are activated.

Real-Time Organic Vapor Monitoring: Real-time monitoring of total organic vapor was conducted using two TVA 1000 Toxic Vapor Analyzers (Foxboro, Foxboro, MA). Each TVA contained both a Flame Ionization Detector (FID) and a Photo Ionization Detector (PID) for the detection of volatile organics. Both the FID and PID detectors were used in each TVA and were programmed to record measurement responses once every 4 seconds. The sample inlet to one TVA was located above the auger and adjacent to the DataRAM inlet. The second TVA inlet location alternated between the screed operator position and the paver operator position (adjacent to the respective Grimm Dust Monitors). The alternation pattern was randomly generated prior to the start of the field evaluation. Difficulties encountered with the TVAs included unknown response variation due to humidity, instrument drift, and airborne concentrations of non-auger and non-HMA sources of organic vapor. The inclusion of short-term sampling periods and the addition of multiple span checks helped to minimize the impact of these difficulties. Due to its increased sensitivity over the

PID, only the FID measurements were used to determine the organic vapor control efficiency as detected above the auger. The PID measurements were available as a backup, in the event of FID failure.

Wind Speed And Temperature: Two portable Hygro-thermo Anemometers, Model HTA 4200 (Pacer Industries, Chippewa Falls, WI), were used to measure and log the crosswind (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 four seconds.

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

An indeterminate variable for all of the exposure measurements was the impact of varying background concentrations, environmental variables, and a unique mix recipe (compared to the previously observed paving sites). The Roadtec field evaluation was unique in that it was the only evaluation to be conducted along a busy interstate highway or during night paving operations. Another feature to the Roadtec evaluation was that the second of two utilized HMA recipes (12.5 mm Open Graded Friction Course (OGFC) D-mix) included a 6.0 percent polymer modified asphalt content. The application temperature for this mix was an average 30 degrees F greater than that observed for the first mix recipe. The result was an increased level of fume and a previously unseen stringy residue that deposited throughout the paving area. When the wind direction blew into the rear of the paver (Mix 2 in Appendix B), significant amounts of fume appeared to enter the sampled work areas from the freshly laid HMA surface behind the paver. This resulted in a non-auger source of fume that was unaffected by the engineering control (see Figure 3).

One way to reduce unknown variable effects is through shorter sample periods collected closer in time. In this way, any background and environmental effects would influence the control-on and control-off testing scenarios in a similar manner. In a modification to the evaluation protocol, the Roadtec field evaluation dedicated a significant portion of the evaluation to short-term sampling, thus increasing the available precision for the resulting point estimate reductions due to the engineering control.

Figure 3. Freshly laid HMA surface became a noticeable non-auger source of asphalt fume during one of the mix recipes. Wind blowing into the rear of the paver carried this fume into the evaluated work areas and adversely affected control reduction results.

ENGINEERING CONTROL DESIGN DESCRIPTION

The Roadtec phase two (field) evaluation was conducted on a single engineering control installed on a Roadtec Model RP 180-10 asphalt paving machine. The tested design consisted of twin exhaust hoods mounted above the auger area, one on each side of the auger gear box. Each hood incorporated flanges on the leading and trailing edges of the hood to enclose approximately 70 percent of the top of the auger area. Airborne contaminants were exhausted from the auger area through the use of two hydraulic exhaust fans. Each fan exhausted via a plenum and flexible ducting system to collect asphalt fumes from three pick-up points along its respective side of the auger. The discharge from the two fans combined into a single exhaust stream and exited through an exhaust stack located on the paver deck. The stack discharge point was approximately 6 feet above the paver deck and about 12 feet above the ground.

The Roadtec hood design focused upon capturing the fume originating from that portion of the auger area bounded by the width of the tractor. Combined with the high-backed screed design, the resulting enclosure over this portion of the auger appeared very effective at minimizing airflow disturbances, yet still allowed visual access to monitor HMA material flow. 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. In this position, fumes and vapors near the end of the auger were virtually non-controlled and ambient winds had an increased opportunity to disrupt fume containment within the auger area. The Roadtec design included two capped duct connections (one per side) to allow for the addition of a hood over the extended portion of the screed. Use of this feature was not observed during this evaluation.

DATA RESULTS

Wind Speed and Temperature

The HTA instruments that recorded wind speed and temperature were located at the screed operator and paver operator locations. They were oriented such that the reported measurements represented the velocity component of the wind blowing perpendicular to the direction of paver travel. Median wind speeds were calculated for each control setting used in the randomization. The data do not indicate a clear relationship between wind speed and measured concentration of particulate or vapor. Little difference (less than 0.4 degree F) in average temperature was found between control-on and control-off when 5-minute periods (before and after a control setting change) were studied. Five minute periods were selected since temperature differences should appear quickly after a change in control setting. Median temperatures were used for this comparison.

SF_6 Determinations

There were a total of seven control-on runs in which SF_6 determinations were made. Multiple determinations were conducted and averaged within each run, resulting in a total of seven control flow rate and average efficiency estimates. The average control exhaust flow rate was 1940 cfm. The average of these was a 94 percent reduction. The lower 95 percent confidence point for the true efficiency was 89 percent. Thus, for the SF_6 determinations, the true efficiency of the engineering control equipment can be said to be greater than 89 percent with 95 percent confidence. The SF_6 evaluations were treated as a separate experiment. Due to its reduced variability, the 95 percent lower confidence limits (LCL) were used as opposed to the 80 percent limits used when evaluating reductions in environmental contaminants.

Environmental Contaminants

Roughly 75,000 data points were statistically evaluated as a result of the 18-hour 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 Total Part	IH BSF	Grimms Aerosol	Grimms Upper 25%	TVA Vapor	TVA Upper 25%	IH Total PACs	IH Upper 25%
Reduction Estimate	75	41	77	72	85	55	82	14	13	34	26
Indiv. LCL[1]	71	37	70	65	81	43	75	10	6	16	14
Simul. LCL[2]	63	31	48	39	66	13	57	1	0	0	0

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

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

DATA DISCUSSION

The Roadtec engineering control evaluation was hampered by several factors that added experimental variability and limited sampling opportunities in an already challenging investigational environment. The limited sampling opportunities allowed circumstances such as the non-auger sources of fume in mix 2 to have a greater proportional impact upon overall performance results than what may have resulted from a more traditional field evaluation. Despite these limitations, many of the performance indicators for the Roadtec engineering control are very encouraging.

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

Wind Speed and Temperature

The lack of an identified numerical correlation between the cross-paver (perpendicular to direction of paver travel) wind speed and observed concentrations at each control setting indicates that there are additional variables contributing to 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. In the case of the Roadtec evaluation, the recorded video footage reveals that the predominant wind directions were parallel with direction of travel.

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

Qualitatively, a more dramatic temperature reduction was observed at the paver operator positions than the quantitative data would indicate. This was evident by the paver operator's use of his jacket during the night paving activities. When the engineering control was not activated, the warm air escaping from the auger area lead the paver operator to remove his jacket. Once the engineering control was activated, the operator re-donned his jacket to keep warm. This cycle continued throughout the cooler, night-paving portion of the study.

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

SF_6 Determinations

The result of the SF_6 evaluation procedure ($\eta = 94\%$ capture efficiency) reveals that the engineering control performed very well at capturing the tracer gas supplied into the auger area. It is important to note, however, that the SF_6 testing protocol allows the observer to identify performance reductions under short-term, ideal conditions which are very close in time. This generally produces performance data whose results are more optimistic than the protocol's other evaluation methods. Another issue to consider when evaluating the tracer gas results is that these values solely reflect the engineering control's ability to control airborne contaminants at the four points of SF_6 injection into the auger area. By comparison, the other evaluation methods detect airborne contaminant concentrations regardless of their source. For example, the fume and vapor that were generated and released during extended screed paving could not be represented by these tracer gas performance results.

Environmental Contaminants

Auger Area--

The results depicted in Table I indicate that the engineering control captured and removed 79 percent of the asphalt fume, based on the average reduction for DataRam, total PAC, and BSF samples, generated within the auger area. There is general consistency among the two particulate methods and the total PAC method (η = 72-77%). Perhaps the BSF results were moderately higher (η = 85%) because this method is more specific for asphalt fume and is less-affected by ambient or non-paving sources of contaminant. Another explanation is the presence of a low value for the control-off total particulate sample which was averaged with the other values. The results for controlling organic vapor (TVA) also show a significant reduction in escaping contaminant (η = 41%) although not as impressive as the other evaluation methods. This reduced performance for the TVA is consistent with results seen at other field evaluations and is likely associated with organic vapor contamination originating from sources other than the auger area.

Screed/Paver Operator--

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

The engineering control source reduction lead to an operator and screed worker average reduction of 45 percent, based on the average reduction for Grimm and total PAC samples. Since the concentrations observed at the non-auger locations averaged roughly 5-fold lower than those observed immediately above the auger (based upon comparison of IH Total PAC results), the lower control efficiency at the non-auger positions was believed to partially result from the natural control-effects produced by environmental factors. In other words, when the wind and environmental factors effectively reduce contaminant concentrations, there is less opportunity for the engineering control to affect exposures. When the environmental factors are less effective in controlling the removal of auger source emissions, such as during a stagnant wind condition, the worker-area concentrations increase. Under these conditions, the contribution of the engineering control becomes more important. As a follow-up to this concept, the data were analyzed to determine what contribution the engineering control provided when the environmental factors were not as effective (i.e., when work area exposures were at their highest.) For this analysis, the data were analyzed to determine the engineering control's efficiency at reducing the occurrence of the highest 25 percent of fume exposure concentrations. These results (see Table I) indicate that the presence of the engineering control effectively reduced the occurrence of higher-level concentrations at the screed and paver operator positions by 82 percent when considering the particulate data but only 26 percent, when considering the total PAC data. The discrepancy in these results is based largely upon the limited amount of total PAC data available. Only 11 pairs of non-auger IH samples were available for evaluation. The upper 25 percent boundary limits this analysis to only three pairs of samples, all of which happened to be collected during the worst period of non-auger exposure reductions (mix 2 as defined in Appendix B). In contrast, the upper 25 percent results for the non-auger particulate data have significant representation from the best period of non-auger control reduction (mix 1).

Interpreting the results for the TVA at the non-auger positions is a difficult task. As discussed previously, the TVA's FID detector is a non-specific detector, (i.e., the same concentration of two different organics can generate dramatically different instrument responses) thus it is not possible to determine the source, identity, or actual concentration of the measured contaminant given the available data. It is also interesting to note that the upper 25 percent reduction shows little difference from the results for all of the non-auger TVA data (η = 13 and 14% respectively), thus indicating a persistent measurement response only minimally influenced by either engineering control or environmental variables.

Given the inconsistencies between the TVA data (η = 14%) and those observed using the Total PAC and real-time particulate methods (η = 34 and 55% respectively) and given the physical characteristic differences between the organic vapor monitored by the TVA and the asphalt fume particulate, NIOSH considers the TVA results at the non-auger positions to be non-representative of the exposure reductions to asphalt fume.

CONCLUSIONS AND RECOMMENDATIONS

The scope of this report is limited to the Roadtec phase two (field) evaluation of a single engineering control installed on a Roadtec Model RP 180-10 asphalt paving machine. On average, the Roadtec design was successful in capturing and removing 79 percent of the asphalt fume (DataRam , PAC, and BSF samples) originating from the auger area. The reduction in fume escaping from the auger resulted in an average reduction of 45 percent within the screed and paver operator work areas. During those periods when environmental factors were not as effective in reducing area concentrations (i.e., when work area exposures were at their highest), the engineering control provided an average fume exposure reduction of 54 percent (real-time particulate and total PAC) although these results are sharply limited by the sparsity of total PAC samples collected. These performance values represent an achievable level of performance by the evaluated engineering control operated under the conditions observed during the Roadtec engineering control evaluation. The Roadtec evaluation was the fourth of six field evaluations to be conducted as part of the engineering controls research partnership. Although the testing methods used had only a minimal history in the challenging environment of asphalt paving, there was sufficient experience to warrant some modifications in the overall testing protocol. Knowledge gained during this evaluation resulted in further limited changes to the evaluation protocol and potentially impacted subsequent evaluation results. Lastly, many of the environmental and process variables were unique to the Roadtec 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 Roadtec field evaluation completed an important step in this process by successfully demonstrating a 79 percent capture of the auger-source asphalt fume and by reducing workers' exposures by 45 percent. Effective July 1, 1997, Roadtec began providing engineering controls as standard equipment on all of their new highway-class pavers. As the Roadtec engineering control is adopted into the industry, NIOSH recommends the following: (1) Monitor the worker/contractor acceptance of the current/future auger-area enclosure designs and incorporate design changes if undesirable field-modifications are observed; (2) Monitor field conditions of asphalt paver engineering controls to determine how well the control design stands up to the rigorous demands of a paving environment; (3) Modify or supplement the existing hood enclosure to minimize escaping fume when the screed is extended beyond the width of the paver; and, (4) Consider developing a control approach to minimize fume exposures originating from the material transfer of HMA into the receiving hopper.

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

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APPENDIX A

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

PHASE TWO (FIELD) EVALUATION PROTOCOL

ASPHALT PAVING FIELD EVALUATION PROCEDURE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

For each Hygro-thermal Anemometers:

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

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

For each Foxboro TVA 1000:

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

3. Aerosols: The MIE, Inc., DataRAM Real-time Aerosol Monitor and two Grimm Dust Monitors will measure and record respirable (less than or equal to ($\leq$) 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 $\leq$ 10 microns.
- Set the particle count to particles $\leq$ 10 microns.
- Position the Grimm in the desired monitoring position.

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

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

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

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

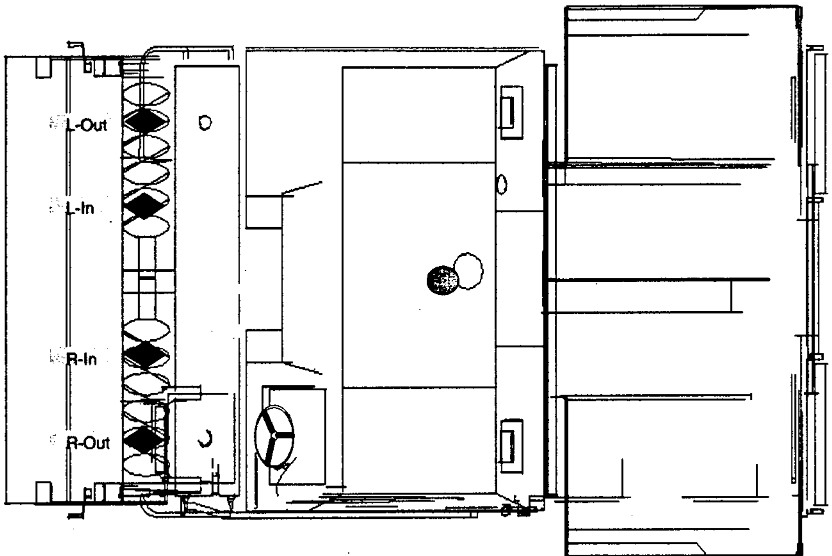
- Calibrate sampling pumps to flow at 2 lpm.
- Construct pairs of sampling trains for eight area and three personal sampling positions (total of 22 samples per day).
- Color code each sampling train: red=uncontrolled, blue=controlled sampling scenario.
- Assign one red and one blue sampling train to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

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

Additional Measurements:

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

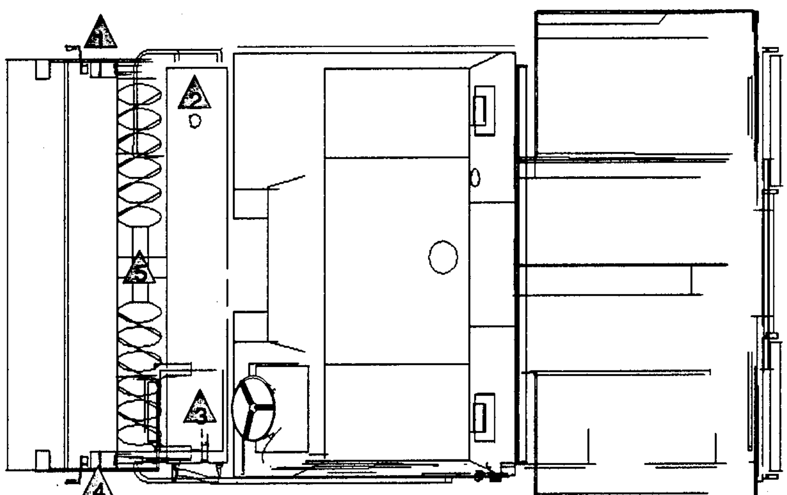
Figure 1: Tracer Gas Dosing And Sampling Locations



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

B&K Monitoring Point Within Engineering Control Exhaust Stack

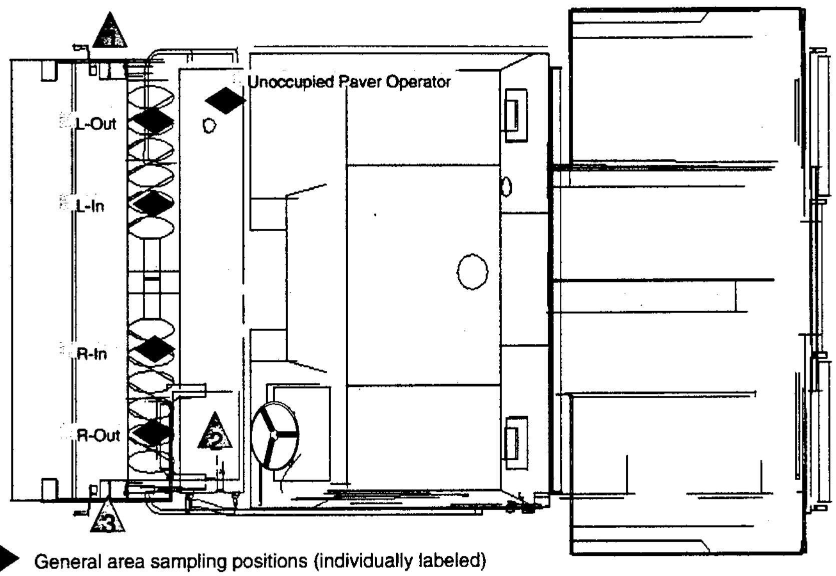
Figure 2: Real-Time Sampling Locations



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

*-Parenthesis denotes rotation among multiple positions

Figure 3: Total-PAC Sampling Locations



General area sampling positions (individually labeled)

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

ATTACHMENT A

POLYCYCLIC AROMATIC COMPOUNDS AS A CLASS PROCEDURE

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.

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

APPENDIX B

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

ROADTEC PHASE TWO FIELD EVALUATION

STATISTICAL DESIGN AND DATA ANALYSIS

ROADTEC (GEORGIA)

EXPERIMENTAL DESIGN

The data were collected in periods of different length. See **Figure 1** for the ordering that was followed. There were shorter length time periods and longer length time periods. The **longer periods were needed for the industrial hygiene** samples, and **the shorter periods** were required to increase the precision of the difference between the control-on and control-off periods **for the real-time samplers**. In Figure 1 "short" designates a set of short-time periods, and "long" designates a long-time period. A period consisted of a pair (control-on, control-off). Because of problems with the weather and the HMA batch plant, **all sampling was done during one 18-hour period of time. The intention was to randomize the order of control-on and control-off in each pair. However, the last eight pairs were mistakenly done according to the same randomization -- (control-off, control-on), followed by the reverse ordering, and then repeating these orderings three more times. Since eight pairs is less than half of the number of pairs used in the analyses of the affected samples, we do not believe that this procedure significantly affected the overall results.**

Two different HMA recipes were used during the evaluation. During the second recipe the direction of paving changed so that the data are divided into three sets, set one for the first HMA recipe and sets two and three for the second HMA recipe, taking into account the change in direction of paving. In this appendix, the three sets are referred to as Mix 1, Mix 2, and Mix 3. For purposes of vapor (via TVA) sampling at the screed and operator positions, the periods in the short-term were designated as either screed or operator samples. Since only one TVA instrument was available for sampling at these two locations, the inlet to the TVA was placed at either the screed or operator position, according to the randomization scheme. In the long-time periods, the TVA continued to be randomized between screed and operator sampling, even though the control setting was unchanged.

Although we call the periods either "short" or "long," **short periods were not all of the same length and long periods were not all of the same length**. The asphalt was delivered to the paving machine in a continuous fashion. Short-time periods at one control setting lasted no less than 4 minutes.

METHODS FOR DATA ANALYSIS

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

real-time measurements. (These included vapor and particulate at the auger and away from the auger.)

For the **industrial hygiene samples**, each of which is collected for a period of not less than 55 minutes, the average of each type of sample was used, rather than the median. **Because the result from each sample is a time-weighted average over a relatively long period of time (compared to the short-term samples), the sample determinations themselves adjust for extreme values that occur in the course of sampling, and the average rather than the median seems appropriate.** This average was taken over all locations sampled during the control setting. The industrial hygiene samples included total PAC at the auger (four locations), total PAC away from the auger (two or three personal samples and four area samples), and total particulate/benzene soluble fraction (BSF) analyses for samples at the auger (four locations).

2. Another question concerns whether to use all measurements for each consecutive set of determinations at a control setting. There are two different issues here. One is that for measurements at one control setting, a period of time is required before an equilibrium level is reached. This is clear from the auger vapor measurements made at the control-off setting in Figure 2. Another issue is that since this was a continuous paving process, there was usually no break in the work between changes in control setting. This is clear in Figure 3, in which the control-off setting in pair 4 is really just a continuation of the control-off setting in pair 3. Whereas it takes some time for the control-off setting in pair 2 to reach a settled level, the control-off setting in pair 4 is already at that level. On the other hand, both control-on settings in pairs 3 and 4 require many measurements to decrease to their final loadings.

A simple way to deal with these problems is to delete measurements after a change in control setting or after an interruption in paving. Also, **because there may be uncertainty about the exact time that paving starts or stops, a half minute of measurements was deleted after the start of a new control setting or after the resumption of paving after a break of at least 25 seconds in paving activity. Analogously a half minute of measurements was deleted prior to the control setting change or stop in paving.** This deletion policy applies to all days of data collection. **This was done for all real-time determinations except the GRIMMs, which were used for particulate measurements away from the auger.** The GRIMMS are different because they record a determination every minute. With so few determinations for the relatively short periods of this study, it makes sense to **use all the GRIMM data that we can for those measurements which have at least half their minute sampling time in the particular control setting under consideration.**

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 section 'Determining Length of Period' contains estimates of control effectiveness for vapor and particulate at the auger, as a function of number of seconds deleted after a change in control setting. **When up to 15 minutes of data are used**

from each control setting, the deletion of a half minute at the beginning and end of the segment produces estimates that differ little from those with longer deletion times.

3. The data included two long-time pairs of (control-on, control-off). Our thinking is that **determinations close together in time are more similar in the uncontrollable variables.** We had to decide how far in time before and after the control setting change we must include data for computation of the medians. 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 selected periods were 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 a 15 minute interval would include measurements between 9:45 and 10 a.m. If the first control-on determination was made at 10:45 a.m., then a 15 minute determination would include measurements between 10:45 and 11:00 a.m. The comparisons indicate that by approximately a half hour duration the estimated effectiveness of the control was stable and did not change much for longer duration. **For the results presented here, half hour periods were used. Additional explanation is provided in the section, 'Determining Length of Period.'**

4. When the medians of many periods were studied together, it happened that there was **higher variability of the medians as the value of the medians increased. This suggested that the natural log** of the medians was to be used when the data were analyzed.

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

5. Another issue concerned **drift in the FID determinations**. The TVAs were zeroed and were spanned with samples containing no analyte and with samples containing analyte that should have given 100 ppm readings for FID. This spanning was carried out both at the beginning and at the end of the day. This allowed correction for drift in the zero responses of FID, by assuming linear drift of the zero response between the two end points. Instead of basing the linear drift upon the elapsed time between the endpoints, it was based on the cumulative fraction at each measurement of the total vapor measured between the two span points. Drift in the 100 ppm determinations was also assumed to be linear between the two endpoints, which assumption allowed for determination of a factor for converting the 100 ppm responses at a particular sampling time t to the equivalent responses at the initial 100 ppm spanning time (t=0). These factors were applied to the zero-corrected FID determinations made at time t to convert them to the equivalent determination at time t=0, after which the initial instrumental response to zero

span gas was added on. **Thereby, changes in readings over time to the same air concentration would be corrected for.**

6. For the real-time data, **ln(median)s were analyzed via analysis of variance methods**, in order to obtain an estimate of the ratio of control-on to control-off. These **ln(median)s are then analyzed via analysis of variance methods** in order to obtain an estimate of the ratio of control-on to control-off (by exponentiating the estimated difference [ln(control-on) - ln(control-off)]). The quantity of interest is 1 minus the estimated ratio, which is the estimated reduction due to the control-on, or (control-off median - control-on median)/ (control-off median), which is converted to percent reduction by multiplying by 100. The models used are different for different kinds of measurements. **For the real-time particulate 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 the same sample type. For the total PAC away from the auger, both area and personal samples are included in the average. Because the industrial hygiene samples, total PAC or weighing samples, were long-time samples done simultaneously, it was possible to carry out a combined analysis of these data. **The control effectiveness was estimated by including all sample types in the same split-plot analysis, and obtaining a separate estimate for each sample type, but pooling the residual variances so as to use a better estimate of the sub-plot variance, with more degrees of freedom**. This seemed acceptable, since the bulk of the variability of the measurements is sampling variability, which was thought to be similar, even though the total PAC and the weighing methods are quite different. The whole plot error is due to the variability of control setting differences over mixes. The sub-plot error is due to variation unexplained after adjustment for sample type differences and sample type differences over control settings.

7. As might be expected, reduction due to the control is greatest for the auger samples. A suggested alternative for the non-auger particulate samples, both real-time and total PAC, was carried out. **This was to estimate the percent reduction for the periods with the highest 25 percent control-off values**. For the total PAC, these are the highest 25 percent of the individual location total PAC control-off determinations away from the auger. For the real-time particulate or vapor, these are the highest 25 percent of the control-off medians, where operator and screedman locations are treated individually. **The data are analyzed as a split-plot kind of design. The standard deviation for the control-on effectiveness for the highest 25 percent can be obtained from the split-plot error. For the total PAC data the split-plot error is due to the variability of control effectiveness over mixes; for the real-time data it is due to the variability of control effectiveness over pairs within mixes.** The results from these analyses can be interpreted as follows. Since the observed reduction is confounded with uncontrollable

factors such as wind speed and direction, the highest control-off measurements may occur where such factors are not effective in reducing the contaminant. Thus, **the reduction here is of interest, since it may** indicate what can be expected when environmental control is not present.

8. For many of the comparisons that follow, the aim was **to establish confidence limits that hold simultaneously for all comparisons at the 80 percent confidence level at the auger and at the non-auger locations and also for the IH samples. Thus, for all comparisons simultaneously, we can say that the error rate is 20 percent.** The probability that any confidence interval statements are in error is no more than 20 percent. **Altogether if eight comparisons were allowed for, then each would be allowed a 2.5 percent error rate. Since the error rates add, the overall error rate will then be no more than 20 percent**. The choice of an overall 20 percent error rate is somewhat arbitrary. Twenty percent might be thought to be acceptable since many factors in this study are not controlled. **Alternatively, we could consider each comparison of control-on versus control-off as a separate test**. The reason to control for the overall error rate is that, although the measurements may each be of a considerably different nature, they are all correlated since they are all taken at the same time. Together they present different aspects of the workplace exposure to the particulate and fumes produced by the paving process. **Because in a less ambitious evaluation, only one kind of measurement might be taken or only one kind of measurement might be of interest, 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 to environmental testing for particulate and vapor, 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 efficiency is 93.61. The estimated variance is 34.117. With seven measurements, this yields a standard deviation of the mean of 2.208. Thus, **the 95 percent lower confidence limit on the true efficiency is 93.61 - 1.943 (2.208) = 93.61 - 4.290 = 89.32**, where 1.943 is the Student's t 95 percentile for 6 degrees of freedom. **Thus, the true efficiency can be said to be >89.3 percent with 95 percent confidence.**

EFFECTIVENESS OF CONTROL AT AUGER

The results for the TVA analyses of FIDs and PIDs at the auger and of the RAM counts 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 period and by average over all periods for the three kinds of samples.

The percent reduction varied considerably over periods for particulate and very little for the vapor. **For all data the percent reduction based on particulate(RAM) data was about 75 percent. The lower (simultaneous) 80 percent confidence limit was about 63 percent, and the lower (individual) 80 percent confidence limit was about 71 percent.** The results for mix 3 were quite different from the other mixes, much lower. For the vapors there was more consistency in the results over the entire day of sampling. The average reduction was about 41 percent, with a **80 percent lower (simultaneous) confidence limit for vapor of about 31 percent reduction, and a lower (individual) 80 percent confidence limit of about 37 percent.**

The data indicate that **different amounts of contaminant were generated during the different mixes. For both particulate and vapor, the geometric means of control-off increase from mix 1 to mix 2 and from mix 2 to mix 3.** The increase for particulate from mix 1 to mix 3 is more than 4-fold, and the corresponding increase for vapor is about 3-fold.

EFFECTIVENESS OF CONTROL AT SCREED AND OPERATOR POSITIONS

The results for the vapor and particulate measurements at the screed and operator locations are plotted by mix in Figure 5. For the vapor, the percent reductions by mix vary between no reduction and 31 percent. **When combined over screed and operator, the average reduction is about 14 percent. The lower (simultaneous) 80 percent confidence limit is 1 percent, and the lower (individual) confidence limit is about 10 percent.** The reductions for vapors away from the auger are much lower than those at the auger.

For the particulate determinations, there was a GRIMM located near the operator and another GRIMM located near the screedman. The reductions over the first two mixes averaged about **55 percent due to use of the control**. Unfortunately, the length of the working shift extended the length of the internal GRIMM batteries and the results for mix 3 were not observed. **The lower (simultaneous) 80 percent confidence limits for the combined GRIMM determinations was a 13 percent reduction and the lower (individual) 80 percent confidence limits indicated a 43 percent reduction.**

For the **upper 25 percent comparison of particulate**, the estimated reduction of the control, combining both operator and screed samples **was 82 percent. The lower 80 percent**

(simultaneous) confidence limit was 57 percent, and the lower (individual) 80 percent confidence limit was 75 percent.

This estimate depends somewhat on terms included in the statistical model. The estimate of 82 percent attributes the entire difference between control-on and control-off in the upper 25 percent group to being in that group. A more conservative estimate of the difference, which gives equal weight to control means over all mixes, is 71 percent reduction. Given the variability of the data, these are not huge differences (82% vs. 71%). The estimate does not change much if the upper 50 percent is studied, rather than the upper 25 percent. For the upper 50 percent, the estimated reduction varies between 59 and 67 percent depending on the terms in the model. **For vapor the estimated reduction for the upper 25 percent data was about 13 percent, with lower (simultaneous) 80 percent confidence limit of 0 percent, and lower (individual) 80 percent confidence limit of 6 percent reduction.**

IH SAMPLES

Figure 6 is a plot of the percent reduction due to the control, based on the industrial hygiene sample data. **The auger samples gave reduction of about 77 percent. The lower (simultaneous) 80 percent confidence limit was 48 percent, and the lower (individual) 80 percent confidence limit was 70 percent.**

The non-auger data, both area samples and personal samples, do vary between the mixes. As for the real-time samples, the geometric means of the IH samples are higher for mix 2 than for mix 1. However, the reductions in mix 2 are much lower than those in mix 1. **The average reduction, over both mixes for which there are data, and over both breathing zone and area samples, was about 34 percent. The lower (simultaneous) 80 percent confidence limits are zero, and the lower (individual) 80 percent confidence limits are about 16 percent.**

Geometric means for the IH sample data are shown in Figure 7. The figure indicates that for all sample types the mix 2 geometric means are higher than the mix 1 geometric means.

The analysis of the upper **25 percent total PAC data (see Figure 8) yields an estimate of 26 percent. The lower (simultaneous) 80 percent confidence limit shows no difference between control-on and control-off, and the lower (individual) 80 percent confidence limit indicates 14 percent reduction.**

From Figure 8, it is apparent that the estimate depends on the choice of upper 25 percent rather than upper 50 percent, say. It may be that the failure to find greater reduction for the upper 25 percent control-off pairs is due to the relatively narrow range of the individual control-off values. Excluding the lowest and highest control-off pairs, the control off measurements vary by less than a factor of 3.

(Recall that horizontal axis in Figure 8 is on the natural log scale, and the difference between the second highest and second lowest is less than 1; e^1~2.7.) Had there been a third or fourth set of IH samples, there might have been more variability among the control-off determinations. It turned out that for the non-auger data, the mix 1 reduction estimates are higher than those for mix 2. When the reduction of the upper 25 percent of mix 1 samples are compared with the reduction for the lower 75 percent, the reduction is 63 percent compared to 50 percent.

The total particulate data (samples collected above the auger) yielded estimates of 72 percent reduction due to the control, with lower (simultaneous) 80 percent confidence limit of 39 percent, and lower (individual) 80 percent confidence limit of 65 percent. For the benzene solubles, the estimated reduction was about 85 percent, with a lower (simultaneous) confidence limit of 66 percent and a lower (individual) confidence limit of 81 percent. There was a zero value for BSF for control-off and both the control-off and control-on were removed from the computations. (It is not clear what to do with zero values when the log is taken.) The corresponding total particulate samples did produce positive values, though they were low. They were retained. This difference in handling those two pairs seems to account for much of the difference between reduction based on BSF or total particulate. When the pair is removed from the total particulate samples, the estimated reduction changes from 72 to 79 percent. Since we do not have a non-statistical reason to remove these pairs (there is nothing on the sheet to indicate that the samples were of questionable value), it may make sense to handle the pairs differently for BSF and total particulate. The total particulate sample pair was retained and used in the average.

The IH data do allow us to make another estimate of the efficiency of the control for vapors. The filters that were used for gravimetric analyses had tube backups. These tubes should collect just vapor since the particulate is extracted via the filters. Thus, the efficiency of the control can be compared based on the backup tube data (vapors) versus the filter data (particulate). The accompanying Figure 9 displays the efficiency by sampling period and location. The efficiency based on the benzene soluble data was never lower than 75 percent with an average value of about 85 percent. Note that these are all individual sample results. Thus, the results are close to the average reduction based on the real-time auger particulate samples for mixes 1 and 2. **Except for the right inside and right outside samples of mix 2 the results based on backup tube determinations are only a little lower than the results based on benzene solubles.** The two exceptions are much lower for which there is no reason. If all four locations for mix 2 are averaged, the result is about 55 percent reduction, considerably higher than the average real-time vapor results for mix 2.

TEMPERATURE AND WIND MEASUREMENTS

The HTA instruments located at the screedman and operator locations were used to measure temperature and wind speed. **Little difference (less than 0.4 degree F) in average temperature was found between control-on and control-off when 5-minute periods (before and after a control setting change) were studied.** Five minute periods were used, since we believe that temperature differences should show up quickly. As in the other comparisons, median temperatures were used for this comparison based on the pairing scheme described above.

Median wind speeds were calculated for each control setting used in the randomization. These determinations and the temperature determinations were made by two HTA instruments, located near the GRIMMs at either the screed positions or the operator positions. **The data do not indicate a clear relationship between wind speed and measured concentration 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%	Vapor- non auger Real-time	Vapor- non auger upper 25%	Total PAC non auger Indus. Hyg.	Total PAC non auger- upper 25%
EST.	75	41	77	85	72	55	82	14	13	34	26
INDIV. LCL	71	37	70	81	65	43	75	10	6	16	14
SIMUL. LCL	63	31	48	66	39	13	57	1	0	0	0

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 particulate at the auger, then it is appropriate to choose the total PAC or the real-time at the auger and quote results only for that **individual comparison**. If the aim is to obtain an overall picture of all matrices (particulate and vapor) or all types of samples (real-time and industrial hygiene) then the simultaneous confidence intervals are the correct ones to use.

DETERMINING LENGTH OF PERIOD

Results are given below as [ln(con-off)-ln(con-on)] for different length periods and different number of seconds deleted at the start of each control setting:

	Vapor			Particulate		
del. (sec.)	3.75 min	15 min	30 min	3.75 min	15 min	30 min
0	.350(.0703)	.445(.066)	.498(.0728)	1.302(.128)	1.33(.157)	1.336(.158)
30	.396(.0703)	.476(.0633)	.527(.0697)	1.401(.151)	1.365(.167)	1.370(.168)
60	.439(.0731)	.504(.0669)	.554(.0726)	1.468(.173)	1.397(.177)	1.401(.179)
90	.443(.0645)	.506(.0574)	.553(.0646)	1.422(.176)	1.414(.202)	1.419(.204)

For vapor the first minute must experience a lot of change, since the estimate for 3.75 minutes with nothing deleted is 0.351 (about 30 percent reduction), lower than the estimate for a minute or 90 seconds of data deleted (about 36 percent reduction). **The increase in efficiency with increasing duration, as indicated by the 15 minute estimates compared to the 3.75 minute estimates, suggests that there is a short lag in changes between control settings**. Since for 15 and 30 minute duration, the first few minutes represent a much smaller fraction of the total sample, there is less difference due to different deletion times at 15 minutes (between 36 and 40 percent reduction) and at 30 minutes (between 39 and 42 percent reduction), compared to 3.75 minutes. **The difference between 15 minute and 30 minute estimates indicates the effect of the long-time periods, since almost all short-time periods are shorter than 15 minutes**. For the vapor, with long-time periods considered alone, the 15 minute estimate, with 1 minute deleted at the beginning, is about 0.52, compared to 0.77 for the 30 minute estimate (respectively, 41 and 54 percent reduction).

The particulate data are somewhat different. At 3.75 minutes there is some difference between deleting no points and deleting a minute's worth of points - from 1.302 to 1.468 (respectively, 73 and 77 percent reduction). **However, in going from 3.75 minutes to 15 minutes there is little difference in the estimates when no points are deleted at the beginning of the interval. This indicates that deletion of a half minute is sufficient to correct for any lag for particulate.** The 30 minute data do not differ much from the 15 minute data; however, many seconds are deleted. This is because the long-time period estimates do not change much in going from 15 to 30 minutes.

From these analyses, it seems acceptable to stay consistent with previous studies and delete a half minute of samples at the beginning and at the end of each segment of time and use 30 minutes for the long-time periods.

LIST OF FIGURES

FIG. 1:STUDY DESIGN

SHORT-TIME PERIOD AND LONG-TIME PERIODS

MIX 1	MIX 2	MIX 3
S	S	S
L	L	
	S	

L=ONE (CONTROL-ON,CONTROL-OFF) PAIR;
S= SEVERAL (CONTROL-ON,CONTROL-OFF) PAIRS

FIG.2: FID AT AUGER FOR 1 (CONTROL-ON, CONTROL-OFF) PAIR

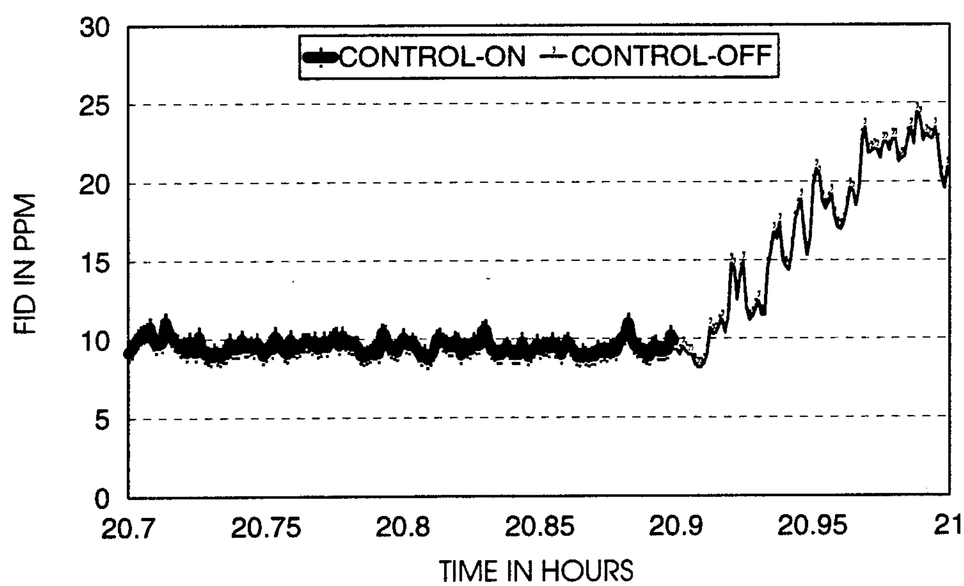


FIG. 3: FID AT AUGER FOR 2 (CONTROL-ON, CONTROL-OFF) PAIRS

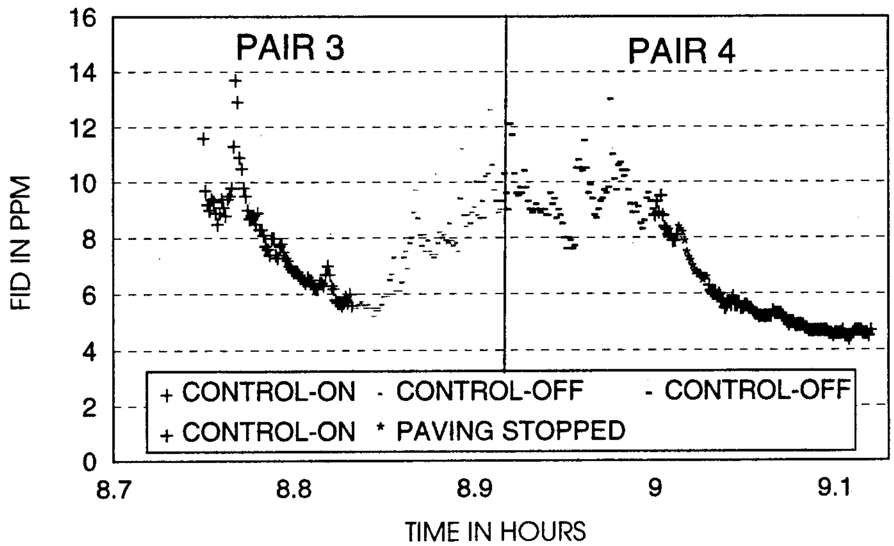
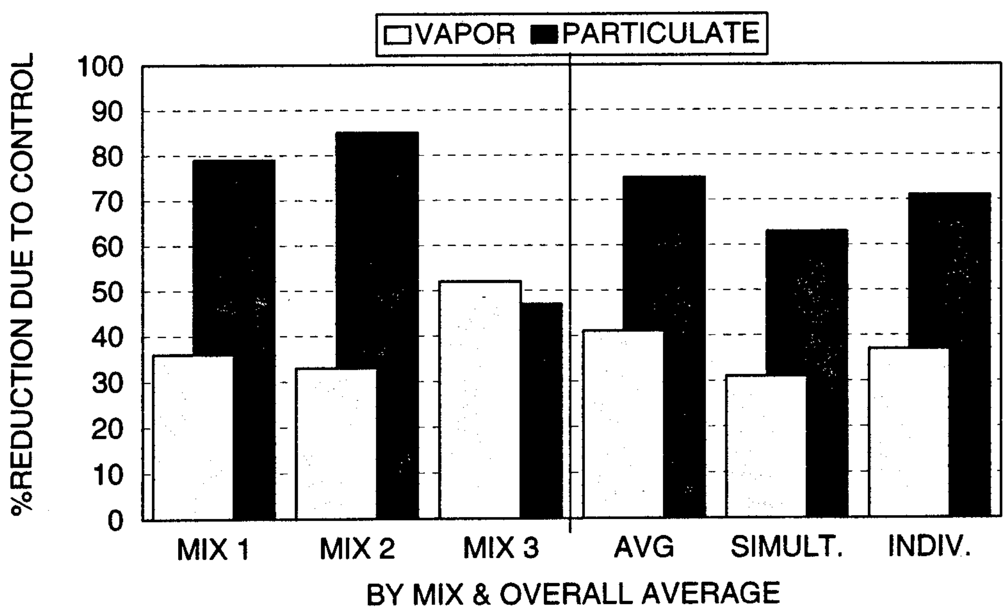


FIG. 4: AUGER: %REDUCTION BY MIX & OVERALL AVERAGE

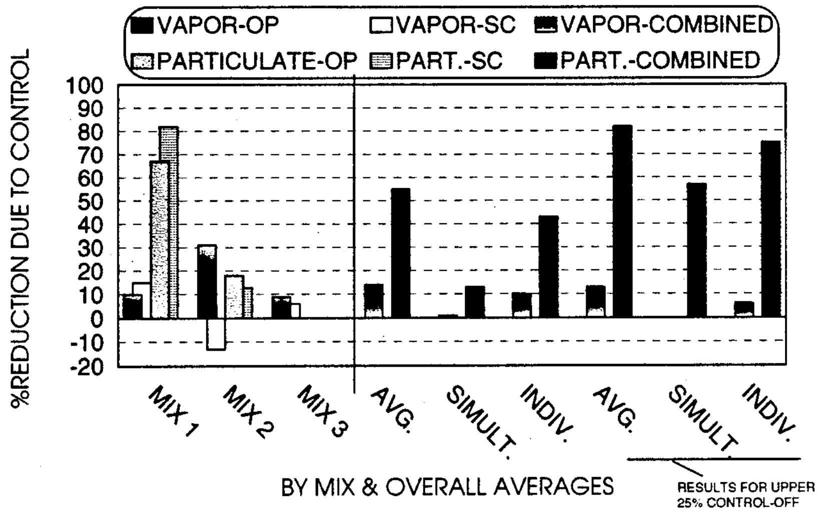
LOWER 80% CONFIDENCE LIMITS, SIMULTANEOUS & INDIVIDUAL



PARTICULATE & VAPOR DIFFER in % REDUCTION

FIG. 5:NOT AUGER: %REDUCTION BY MIX & OVERALL

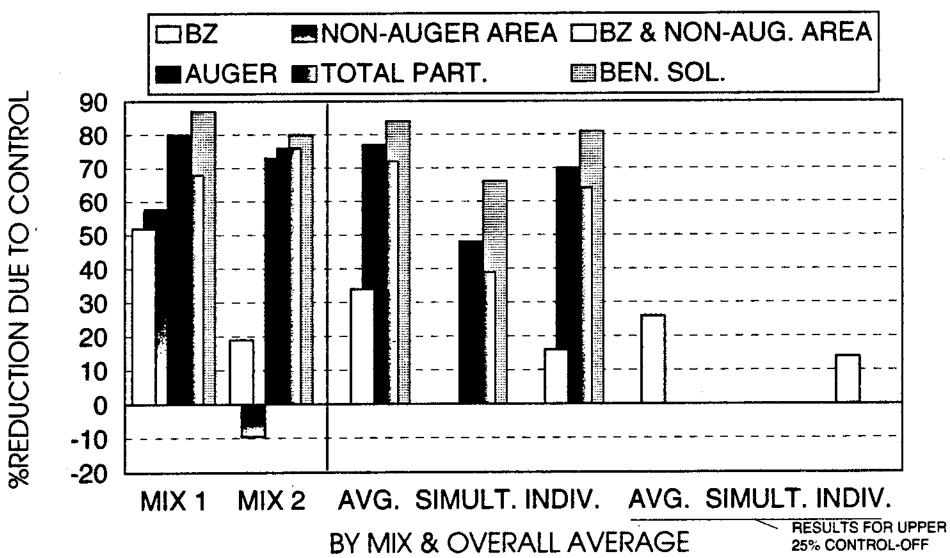
LOWER 80% CONFIDENCE LIMITS, SIMULTANEOUS & INDIVIDUAL



DATA MISSING FOR GRIMMS IN MIX 3

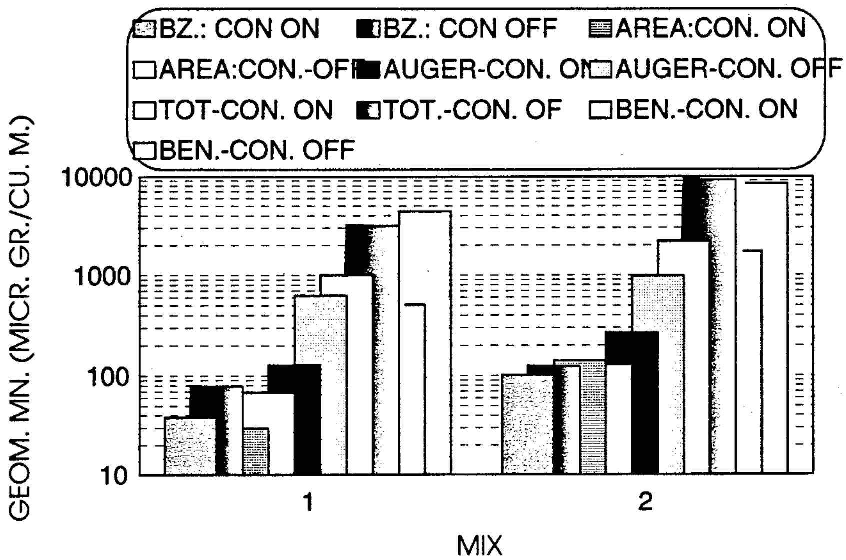
FIG. 6:INDUSTRIAL HYGIENE SAMPLES: %REDUCTION BY MIX & OVERALL AVERAGE

LOWER 80% CONFIDENCE LIMITS, SIMULTANEOUSLY & INDIVIDUALLY



PAC BREATHING ZONE AND NON-AUGER AREA SAMPLES COMBINED FOR AVERAGE VALUE AND CONFIDENCE LIMITS. SIMULTANEOUS CONFIDENCE LIMIT FOR TOTAL PARTICULATE IS 0.

FIG. 7 :INDUSTRIAL HYGIENE GEOMETRIC MEANS



370nm AND 400nm DETERMINATIONS ARE SUMMED;

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

FOR TOTAL PAC AREA & BREATHING ZONE SAMPLES AWAY FROM AUGER

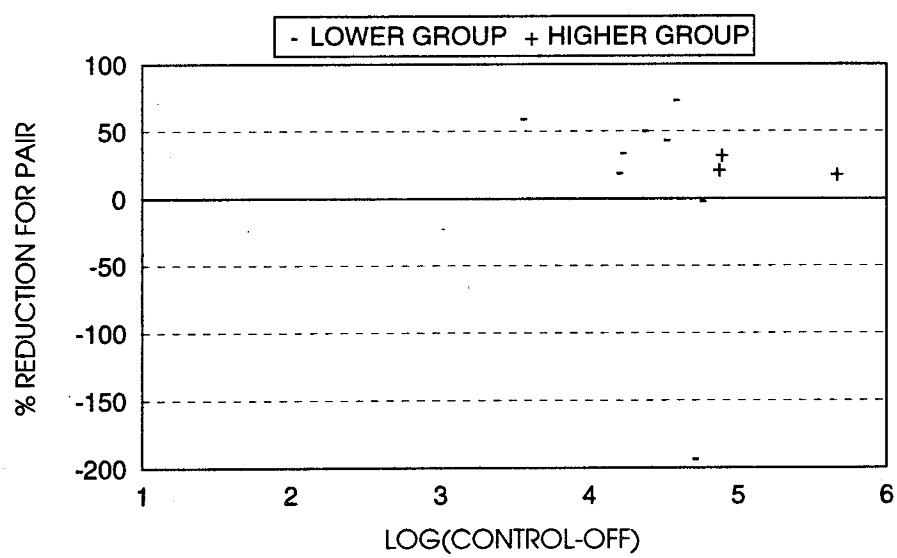
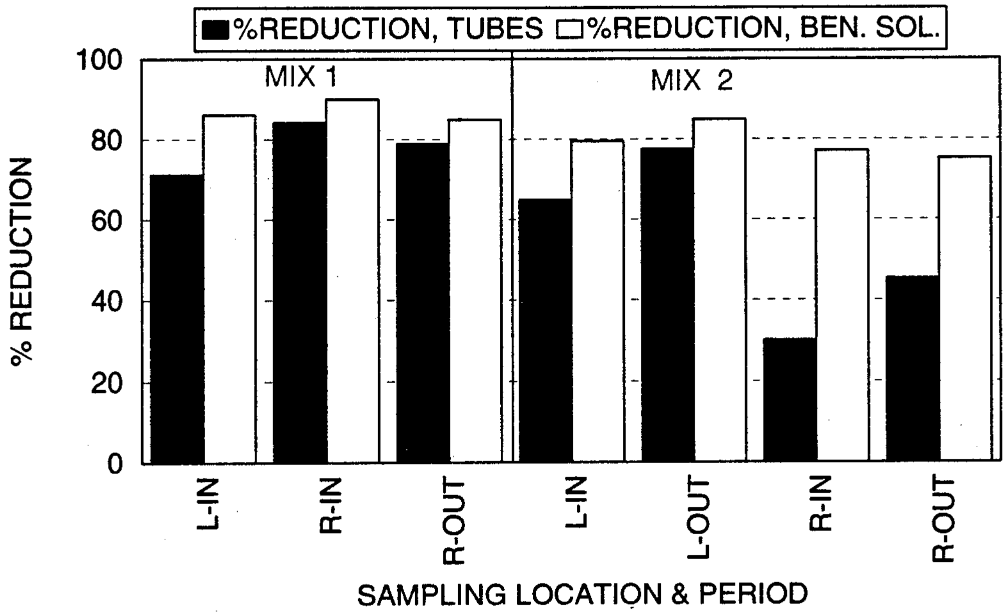


FIG. 9: PER CENT REDUCTION

FOR BACKUP TUBE & BENZENE SOLUBLE SAMPLES AT AUGER



FOR BEN. SOL., 1 OUTLIER AT L-OUT ON DAY 1- DATA EXCLUDED; TUBE DATA SIMILAR TO BEN. AFTER EXCLUSION; TUBE REDUCTION SLIGHTLY LESS THAN BEN AND TOTAL, EXCEPT FOR R-IN AND R-OUT IN MIX 2. NO EXPLANATION.