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**HETA 95-0307-2602**  
**Koester Equipment Company**  
**Evansville, Indiana**

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## PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

## ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Gregory Burr and Aubrey Miller, of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Leo Blade, Calvin Cook, Larry DeArmond, DaeHee Kang, Michael King, Gregory Kinnes, Mike MacDonald, Mike Pederson, Kenneth Wallingford, and Shamekia Washington. Analytical methods were developed by Larry Jaycox, Charles Neumeister, and Larry Olsen. Laboratory analysis provided by Ardith Grote, Robert Kurimo, Larry Jaycox, Leroy May, Charles Neumeister, and Rosa Key-Schwartz. Desktop publishing by Ellen Blythe.

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**Health Hazard Evaluation Report 95-0307-2602**  
**Koester Equipment Company**  
**Evansville, Indiana**  
**December 1996**

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## **EXECUTIVE SUMMARY**

Approximately 285 million used tires are discarded in the United States each year, posing significant health, fire, and solid waste management problems. As one means of reducing these problems, considerable attention has been focused on the use of the scrap tire rubber in highway paving materials. In 1991, Congress enacted the Intermodal Surface Transportation Efficiency Act (ISTEA), which required each state to use a minimum quantity of "crumb rubber modified" (CRM) hot-mix asphalt (HMA) paving material, beginning at 5% of the HMA used in federally funded paving in 1993, and increasing to 20% in 1997 and thereafter. Because of public concerns over the lack of available information on the environmental and human health effects resulting from the use of CRM-HMA, along with the higher initial cost of using this paving material, a temporary legislative moratorium was passed which precluded enforcement of the penalty provisions of the ISTEA legislation. This legislation also directed the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Transportation, Federal Highway Administration (FHWA) to evaluate the potential environmental and human health effects associated with the use of CRM asphalt. The recently passed National Highway System Designation Act of 1995 has eliminated the mandate requiring the use of CRM asphalt but continues to require research concerning CRM asphalt paving.

Approximately 300,000 workers are currently employed in the asphalt paving industry in the U.S. In June 1994, the National Institute for Occupational Safety and Health (NIOSH) entered into an Interagency Agreement with the FHWA to evaluate occupational exposures among asphalt workers. A research protocol developed by NIOSH included the following objectives:

- P Characterize and compare occupational exposures to CRM asphalt and conventional asphalt.
- P Develop and field test new methods to assess asphalt fume exposures.
- P Evaluate potential health effects associated with CRM asphalt and conventional asphalt.

The protocol allows for up to eight individual site evaluations in different geographic regions of the country, enabling investigators to observe different asphalt pavement formulations, climatic conditions, and paving techniques.

One of the greatest challenges in conducting this study is the fact that asphalt is not a consistent product. Asphalt is composed of a highly complex mixture of paraffinic and aromatic hydrocarbons and heteroatomic compounds containing sulfur, nitrogen, and oxygen. The specific chemical content of asphalt products is dependent on the crude petroleum source, production techniques, and process temperatures. The addition of rubber further complicates the asphalt mixture as numerous additional substances present in tires (such as aromatic oils, accelerants, and antioxidants used during tire manufacturing) may become airborne during the asphalt heating and mixing processes. Finally, there is a lack of available air sampling methods and occupational exposure limits for most of the compounds present in asphalt and the rubber tire components.

This report presents the findings from a field survey conducted near Jasper, Indiana, during asphalt pavement construction along Interstate 64 in southern Indiana. The purpose of this report is not to draw definitive conclusions about conventional and CRM asphalt exposures, but rather to provide the site-specific information obtained from the Indiana project.

On July 13–14, 1995, approximately 2,370 metric tons of CRM asphalt were applied by the Koester Equipment Company; on August 22–23, 1995, approximately 3,670 metric tons of conventional asphalt were placed by the same workers. The total weight of rubber in the CRM asphalt (by total weight of the asphalt/rubber blend) was approximately 22%. Of note, recycled asphalt pavement (RAP) comprised 23% of the conventional asphalt formulation but was not used in the CRM asphalt mix. The workplace exposure and health assessment was performed during all four paving days. The evaluation included the collection of area air samples to characterize the asphalt fume emission, personal breathing zone (PBZ) air samples to evaluate worker exposures, and a medical component that included symptom questionnaires and lung function tests.

Asphalt fume exposures have typically been measured as total particulate (TP) and the benzene soluble particulate fraction (BSF). However, since neither of these exposure markers measure exposure to a distinct chemical component or even a distinct class of chemicals, it is difficult to relate them to possible health effects. For example, many organic compounds are soluble in benzene, and any dust may contribute to TP levels. In an effort to address this problem, new or modified analytical methods were developed and included in this study to more definitively characterize asphalt fume exposures. Polycyclic aromatic compounds (PACs), which may be present in asphalt fume, were measured using a new analytical method. Some of the PACs may have irritative effects, while other PACs are suspected to be carcinogenic. In addition to PACs, benzothiazole (a sulfur-containing compound present in rubber tires), along with other sulfur-containing compounds (suspected to be present as a result of the addition of rubber to the asphalt or from crude petroleum used for asphalt manufacturing), were also measured. Benzothiazole is of interest since it may be useful as a surrogate indicator for other CRM asphalt fume exposures, while other sulfur-containing compounds may be associated with respiratory irritation. Samples were collected for analysis of selected organic compounds (toluene, xylene, benzene, methyl isobutyl ketone [MIBK], and total hydrocarbons (measured as either n-hexane or Stoddard solvent). Elemental carbon was measured to determine if diesel exhaust could have contributed to the air contaminants measured at the paving site. The airborne particulate at the paving site was analyzed to determine the concentration of respirable particles. Direct-reading instruments were used to measure carbon monoxide (CO), hydrogen sulfide (H<sub>2</sub>S), sulfur dioxide (SO<sub>2</sub>), and ozone (O<sub>3</sub>). Finally, bulk air samples of asphalt fume were collected at the asphalt cement storage tank located at the hot mix asphalt plant and submitted for mutagenicity testing.

The concentrations of TP, respirable particulate, and BSF varied across survey days but were consistently higher during CRM asphalt paving periods than during conventional asphalt paving periods. Total PAC concentrations above the paver screed were approximately six times higher during the CRM asphalt paving than during conventional asphalt paving. Benzothiazole concentrations above background levels were detected only during CRM asphalt paving. Other sulfur-containing compounds (except benzothiazole) were detected during all paving periods, but concentrations were higher during CRM asphalt paving.

Over 50 volatile organic compounds (VOCs) were detected in the asphalt emissions; the most significant peaks were analyzed quantitatively. The concentrations of toluene, xylene, MIBK, and total hydrocarbons (as either n-hexane or Stoddard solvent) were well below their respective occupational exposure limits. The highest VOC concentrations were measured for MIBK (range 0.12 to 0.92 parts per million) and were only detected during CRM asphalt paving. Trace amounts of xylene and benzene were also detected, and only during CRM asphalt paving. Concentrations of CO, H<sub>2</sub>S, SO<sub>2</sub>, and O<sub>3</sub> were well below their respective occupational exposure limits.

Personal breathing-zone air samples were collected on seven to eight paving workers during each of the four days of sampling. The PBZ samples were analyzed for TP, total PACs, benzothiazole, and other sulfur compounds. The PBZ exposures for TP ranged up to 0.67 milligrams per cubic meter (mg/m<sup>3</sup>) during CRM asphalt paving and up to 0.3 mg/m<sup>3</sup> during conventional asphalt paving. Although TP concentrations were generally higher during

CRM asphalt paving than conventional paving, the accuracy of this difference cannot be easily determined due to the limited number of PBZ samples. All of the PBZ concentrations, however, were well below the current NIOSH recommended exposure limit (REL) for asphalt fume of 5 mg/m<sup>3</sup> (measured as TP).

The PBZ concentrations of PACs (at both 370 and 400 emission nanometers), benzothiazole, and other sulfur compounds were higher during CRM asphalt paving than during conventional asphalt paving. The PBZ concentrations of PAC<sub>370</sub> during conventional and CRM asphalt paving ranged up to 2.8 and 8.7 µg/m<sup>3</sup>, respectively. Benzothiazole, detected only during CRM asphalt paving, ranged up to 58 µg/m<sup>3</sup>.

Nine workers with exposure to the asphalt paving operation (pavers) were recruited for the health assessment. Additionally, ten workers not typically exposed to hot asphalt fume (non-pavers) were recruited for comparison. Serial symptom questionnaires were administered to obtain information concerning the prevalence of acute symptoms (i.e., respiratory, eye, nose, throat, and skin symptoms) in relation to worksite exposures. Serial measurements of peak expiratory flow rate (PEFR) were conducted to evaluate acute changes in lung function in relation to worksite exposures. Two pavers were excluded from analysis of the medical data due to lack of exposure to the paving operation on the first two survey days. One non-paver was excluded from analysis of the medical data due to unreliable and inconsistent responses during the health assessment. Among pavers, the acute symptom survey revealed an almost 2.5-fold increase in the number of reported health symptoms per completed questionnaire, and a 3.5-fold increase in rate of reported symptoms per hour of estimated asphalt fume exposure, during the CRM asphalt paving period as compared to the conventional asphalt paving period. Most notable was the increased reporting of cough and throat symptoms during CRM asphalt paving. The PEFR results at this study site did not show an association between measurable bronchospastic responses and asphalt paving work.

This study showed that asphalt fume and other exposures were below current NIOSH RELs or other relevant exposure limits for those substances with established occupational exposure criteria. Higher concentrations of TP, respirable particulate, BSF, PACs, and other sulfur-containing compounds (except benzothiazole) were measured over the screed during the CRM asphalt paving periods than during conventional asphalt paving periods. Benzothiazole (above background concentrations) was only detected during CRM asphalt paving periods. Acute symptoms were reported by workers in association with asphalt paving exposures, with higher symptom prevalences associated with CRM asphalt paving. Although the higher symptom rates associated with CRM asphalt paving are consistent with the higher area air concentrations measured during the CRM asphalt paving periods, the limited number of both area and PBZ air samples obtained from this one evaluation makes further interpretation of this association difficult. Also, the extent, if any, to which our exposure and health findings may have been influenced by the presence of recycled asphalt pavement during conventional paving is unknown. Presently, NIOSH investigators feel it is premature to draw definitive conclusions from this single site evaluation. Data provided from this evaluation are based on a very small sample size and may reflect production and weather conditions specific to this site. Additional site evaluations may enable more definitive conclusions to be drawn. A final composite report will be prepared after these additional site evaluations are completed.

**Keywords:** SIC 1611 (Highway and Street Construction), asphalt fume, bitumen, crumb rubber modifier, CRM, recycled tires, paving, interstate highways, polycyclic aromatic compounds, PACs, polynuclear aromatic hydrocarbons, PAH, total particulate, respirable particulate, benzene soluble particulate, volatile organic compounds, hydrocarbons, elemental carbon, eye irritation, respiratory irritation.

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## PROCESS OVERVIEW

There are three basic steps in constructing an asphalt pavement – manufacture of the hot mix asphalt (HMA), placement of the mix onto the ground, and compaction. The asphalt mix contains two primary ingredients, a binder which is typically an asphalt cement, and an aggregate which is usually a mixture of coarse and fine stones, gravel, sand, and other mineral fillers. The mix design establishes the proportions of the aggregate materials and sizes to the amount of asphalt cement to obtain the appropriate pavement properties (flexibility, drainage, durability, etc.).

The purpose of an HMA plant is to blend the aggregate and asphalt cement to produce a homogenous paving mixture at a hot temperature so that it can be easily applied and compacted. Asphalt cement is typically received from a refinery by tractor trailer tankers and is transferred into heated storage tanks. Aggregate of different materials and sizes is blended through a series of belt conveyors and a dryer (a heated drum mixer). Once the aggregate is sufficiently blended and dried, asphalt cement is applied so that a continuous thin film of cement covers the aggregate evenly. The finished HMA is then placed in a storage silo until it can be dispensed into trucks that haul the material to the paving site. At the paving site the following equipment is typically used:

**P Tack truck:** A vehicle which precedes the paver and applies a low viscosity asphalt ("tack" coat) to the roadway to improve adhesion prior to the HMA placement.

**P Paver:** A motorized vehicle which receives the HMA from the delivery trucks and distributes it on the road in the desired width and depth. The HMA may be directly transferred from the delivery truck to the paver by: (1) directly pouring HMA into a hopper located in the front of the paver; (2) dumping HMA in a line onto the road where it is picked up by a windrow conveyor and loaded into the paver

hopper; or (3) conveying the mix with a material transfer vehicle.

**P Screed:** Located at the rear of the paver, the screed distributes the HMA onto the road to a preselected width and depth and grades the HMA mix to the appropriate slope as the paving vehicle moves forward.

**P Rollers:** Typically two or three roller vehicles follow the paver to compact the asphalt.

Paving crews normally consist of eight to ten workers. Job activities include a foreman who supervises the crew; a truck dumper (or "dumpman") who coordinates the arrival (and operates the hatches) of the bottom-dump trucks; a paver operator who drives the paver; one or two screed operators who control and monitor the depth and width of the HMA placement; one or two rakers who shovel excess HMA, fill in voids, and prepare joints; laborers who perform miscellaneous tasks; roller operators who drive the rollers; and a tackman who applies the tackcoat. The paver operators and roller operators do not usually perform different jobs, while the screed operators, rakers, and laborers may perform a variety of tasks throughout the workday.

For purposes of this report, workers associated with the asphalt paving operation (i.e., workers with potential exposure to HMA fume) will be referred to as "pavers." This definition may include workers not specifically employed by the paving contractor (i.e., state highway inspectors) but who are associated with the paving operation and could be exposed to HMA fume during paving. Additionally, some workers who performed jobs associated with road construction, but not exposed to HMA fume (i.e., foremen, laborers, heavy equipment operators, and road surveyors), participated as a control group for the pavers and will be referred to as "non-pavers."

## SITE DESCRIPTION

On July 13–14, and continuing on August 22–23, 1995, NIOSH investigators conducted a study near



Jasper, Indiana, during asphalt pavement construction on Interstate 64 by the Koester Equipment Company. The gap between the conventional and CRM asphalt paving surveys resulted from unexpected delays that the paving contractor encountered in preparing this section of interstate highway for the conventional asphalt paving. The same paving crew, consisting of a foreman, a paver operator, two screed operators, two to three roller operators, and one to two laborers, was evaluated throughout the survey. A state highway inspector assigned to this paving project was also included in this evaluation since he remained close to the paving crew throughout the work day.

A summary of the paving activities and equipment used at the I-64 site is contained in Table 1. Both the conventional hot mix asphalt (hereafter referred to as “conventional asphalt”) and crumb rubber modified hot mix asphalt (subsequently referred to as “CRM asphalt”) were manufactured at the same plant from the same petroleum crude source. On this project, the general contractor (Koester Equipment Company) approved the request of the subcontractor who produced the CRM asphalt to accelerate their work from July 24 to July 12, 1995. This resulted in NIOSH evaluating the CRM asphalt paving operations *prior to* conventional paving operations.<sup>1</sup> The CRM asphalt was used on July 13–14, and the conventional asphalt was placed on August 22–23. Koester Equipment personnel placed approximately 300 pounds per square yard (equivalent to a depth of approximately 7 centimeters [2.75 inches]) of open-graded base course on the westbound outer lane of I-64 during the July survey. On August 22–23, the paving contractor placed approximately 5 cm (2 inches) of binder on the outer lane of I-64 westbound (east of the previously placed CRM asphalt).

A viscosity graded asphalt cement, AC-10, was used for the conventional asphalt paving; AC-5 was used for CRM asphalt paving. The crude oil supplier for the entire project was Marathon Oil, Louisville,

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<sup>1</sup> In three previous NIOSH asphalt studies, conventional asphalt paving was evaluated before CRM asphalt paving.

Kentucky. The conventional asphalt mix was an Indiana Department of Transportation (INDOT) mix design consisting of 4% natural sand, 39% No. 9 stone, 34% No. 12 stone, and 23% recycled asphalt pavement (RAP).<sup>2</sup> The aggregate blend for the CRM asphalt mix was 92% No. 5 stone and 8% natural sand. The rubber percentage (total weight of rubber by total weight of the asphalt/rubber blend) was approximately 22%. The granulated rubber was manufactured by the Baker Rubber Company, South Bend, Indiana.

The HMA plant for this construction project, operated by Koester Equipment, was located west of Bretzville, Indiana, approximately 30 minutes away from the I-64 paving site. During both the conventional and CRM asphalt paving, the HMA was hauled to the paving site by dump trucks (average capacity 25 tons). Approximately 2,225 and 1,445 metric tons of conventional asphalt were applied each day on August 22 and 23, respectively. These totals compare to 1,086 and 1,283 metric tons of CRM asphalt placed on July 13 and 14, respectively. The laydown temperatures for the asphalt mixes varied somewhat throughout each paving day and between paving days (see Table 1). The maximum laydown temperatures for the conventional and CRM asphalt mixes were 132°C (270°F) and 135°C (275°F), respectively.

## INDUSTRIAL HYGIENE EVALUATION DESIGN

Previous research efforts by NIOSH investigators and other researchers have attempted to characterize asphalt fume exposures among road paving workers. Asphalt fume exposures have typically been measured as total particulates and benzene soluble

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<sup>2</sup> Although the use of RAP was completely acceptable in this paving contract, the NIOSH investigators were not aware of its use until August 1995. Because the residual AC in the RAP replaces a portion of the virgin AC, the combined AC will have somewhat different characteristics. The industrial hygiene and medical implications from the use of RAP on this NIOSH study are not known.

particulate fraction. Correspondingly, occupational exposure criteria for asphalt fume have been expressed in terms of total particulates and the benzene soluble fraction of the particulates. However, since neither of these exposure markers measure exposure to a distinct chemical component or even a distinct class of chemicals, it is difficult to relate them to possible health effects. For example, many organic compounds are soluble in benzene, and any dust may contribute to total particulate levels. In an effort to address this situation, new or modified sampling and analytical methods were developed and included in this study. Polycyclic aromatic compounds (PACs), which may be present in asphalt fume, were measured using a new analytical method. Some of the PACs are believed to have irritative effects while other PACs are suspected to be carcinogenic. In addition to PACs, benzothiazole (a sulfur-containing compound present in rubber tires) along with other sulfur-containing compounds (suspected to be present as a result of the addition of rubber to the asphalt or from high sulfur crude petroleum used for asphalt manufacturing) were also measured. Benzothiazole is of interest since it may be useful as a surrogate indicator for other CRM asphalt fume exposures while other sulfur-containing compounds may be associated with respiratory irritation. Samples were collected for selected organic compounds (toluene, xylene, benzene, methyl isobutyl ketone [MIBK], and total hydrocarbons (measured as either n-hexane or Stoddard solvent). Elemental carbon was measured to determine if diesel exhaust could have contributed to the air contaminants measured at the paving site. The airborne particulate at the paving site was analyzed to determine the concentration of respirable particles. Air samples were collected for 28 different metals and minerals and direct-reading instruments were used to measure carbon monoxide, hydrogen sulfide, sulfur dioxide, and ozone. Bulk air samples of asphalt fume were collected at the asphalt cement storage tank located at the hot mix asphalt plant and submitted for mutagenicity testing.

## Weather Information

Meteorological conditions were recorded at regular intervals among survey days. The meteorological data included dry bulb and wet bulb temperatures (for subsequent calculation of relative humidity), wind speed and direction, and wet bulb globe temperature (WBGT). Wind speed and direction were measured with a Transportable Automated Meteorological Station (TAMS) manufactured by Qualimetrics. Environmental measurements were obtained at 20-minute intervals using a Reuter Stokes RSS 214 Wibget® heat stress meter.

## Process Information

Process information and operational details were recorded daily by FHWA, State Department of Transportation (DOT), contractors, or NIOSH investigators. This information included the asphalt grade, type of application, crude source, percent rubber, additives, production quantities, application temperature, paving depth, average application rate, site description, and traffic density.

## Area Air Samples

To evaluate worst-case conditions and characterize the asphalt fume, area air samples were collected above the screed auger of the paving vehicle. Background area air samples were collected in the highway median to evaluate the ambient air and possible impact from vehicle emissions. Area samples were collected for total particulate (TP), respirable particulate, PACs, sulfur-containing compounds (including benzothiazole), benzene soluble particulate fraction (BSF), aromatic and aliphatic solvents (based on the qualitative identification of volatile organic compounds via mass spectroscopy), and elemental and organic carbon. Direct reading instruments were used to measure carbon monoxide, hydrogen sulfide, sulfur dioxide, and ozone.

Except for the samples obtained with direct-reading instruments, air samples were collected using calibrated battery-operated sampling pumps with the appropriate sorbent tube or filter media connected

via Tygon® tubing. The area and personal breathing-zone (PBZ) sample concentrations were calculated based on the actual monitoring time (time-weighted average [TWA-actual] concentrations) instead of calculating an 8-hour TWA concentration so that the sampling data could be compared between days that had unequal monitoring durations. Calibration of the air sampling pumps with the appropriate sampling media was performed daily, before and after each monitoring period. Field blanks were collected and submitted to the laboratory for each analytical method.

High volume air samples of the asphalt fume were collected above an open hatch on the asphalt cement storage tank at the HMA plant and are being evaluated at various concentrations for mutagenic activity via a modified Ames testing protocol. The basic analytical procedure has been described by Maron and Ames [1983], except a spiral plater device described by Houk et al. [1989, 1991] is used. The results from these modified Ames tests of asphalt fume will be discussed in a future NIOSH report.

## Personal Breathing-Zone Air Samples

Personal breathing-zone (PBZ) monitoring was conducted on most of the paving crew. These PBZ samples were analyzed for TP and total PACs, including benzothiazole and other sulfur-containing compounds.

## Air Sampling Methods

Table 2 summarizes all of the air sampling methods used in this evaluation. Since sampling for PACs involved a new analytical technique, Appendix A is included to provide additional detail on this method. Appendix B provides greater detail on the draft NIOSH Sampling and Analytical Method No. 5040 for elemental carbon. Appendix C compares the test results obtained from a new combined sampling method (measuring both TP and BSF from the same sampling filter) to the traditional sampling and

analytical methods (also used in this evaluation) which measure TP and BSF on separate filters.

## MEDICAL EVALUATION DESIGN

On July 12, 1995, NIOSH investigators recruited workers to participate in the health assessment, which included a general health and occupational history questionnaire, serial acute symptom questionnaires, and serial peak expiratory flow rate (PEFR) testing. PEFR testing was conducted to evaluate acute changes in lung function. Peak flow refers to the amount of air in liters per minute that can be exhaled through the flow meter in one complete breath.

All workers with exposure to the asphalt paving operation (pavers) were asked to participate in the study. Nine of the 11 pavers volunteered and were included in the health assessment. NIOSH investigators also recruited ten workers (non-pavers) employed at the same construction site, but not in proximity to the asphalt paving operation, to participate in the health assessment for comparison purposes. Initially, five non-pavers were recruited to participate in the study for all four days, however, two workers were not available for days 3 and 4, resulting in the recruitment of five additional non-pavers for this period.

A one-time general health questionnaire was privately administered to each health assessment participant during the study. Each worker was asked about the presence of chronic respiratory, eye, nose, throat, and skin symptoms. Information concerning smoking history and work history was also solicited.

Acute symptom questionnaires were periodically administered to all study participants during their workshift to determine if eye, nose, throat, skin, or respiratory symptoms (including cough, chest tightness, or wheezing) were associated with their

job tasks. Whenever possible, the acute symptom questionnaires were administered before and after each workshift and three times during the workshift, at approximately two-hour intervals during each survey day.

PEFR measurements were made using Wrights portable peak flow meters just prior to the administration of the acute symptom questionnaire. Three exhalations were recorded each time, and the highest of the three recordings was accepted as the PEFR determination. Participants were considered to have significant bronchial lability if the difference between the minimum and the maximum PEFR on at least one day exceeded 20% of that day's maximum PEFR.

## EVALUATION CRITERIA

To assess the hazards posed by workplace exposures, NIOSH investigators use a variety of environmental evaluation criteria. These criteria are exposure limits to which most workers may be exposed for a working lifetime without experiencing adverse health effects. However, because of the wide variation in individual susceptibility, some workers may experience occupational illness even if exposures are maintained below these limits. The evaluation criteria do not take into account individual sensitivity, preexisting medical conditions, medicines taken by the worker, possible interactions with other workplace agents, or environmental conditions.

The primary sources of evaluation criteria for the workplace are NIOSH criteria documents and recommended exposure limits (RELs) [NIOSH 1994], the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) [OSHA 1993], and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs<sup>®</sup>) [ACGIH 1996]. These occupational health criteria are based on the available scientific information provided by industrial experience, animal or human experiments, or epidemiologic studies. It should be noted that RELs and TLVs are guidelines, whereas PELs are

legally enforceable standards. The NIOSH RELs are primarily based upon the prevention of occupational disease without assessing the economic feasibility of the affected industries and, as such, tend to be conservative. The OSHA PELs are required to take into account the technical and economical feasibility of controlling exposures in various industries where the agents are present. A Court of Appeals decision vacated the OSHA 1989 Air Contaminants Standard in *AFL-CIO v OSHA*, 965F.2d 962 (11th cir., 1992); and OSHA is now enforcing the previous standards (listed as Transitional Limits in 29 CFR 1910.1000, Table Z-1-A), which were originally promulgated in 1971. However, some states with OSHA-approved state plans continue to enforce the more protective ("final rule") limits promulgated in 1989. For exposures with evaluation criteria, NIOSH encourages employers to use the 1989 OSHA PEL or the NIOSH REL, whichever is lower.

Evaluation criteria for chemical substances are usually based on the average PBZ exposure to the airborne substance over an entire 8- to 10-hour workday, expressed as a time-weighted average (TWA). Personal exposures can be expressed in parts per million (ppm), milligrams per cubic meter (mg/m<sup>3</sup>), or micrograms per cubic meter (µg/m<sup>3</sup>). To supplement the TWA where adverse effects from short-term exposures are recognized, some substances have a short-term exposure limit (STEL) for 15-minute periods; or a ceiling limit, which is not to be exceeded at any time. Additionally, some chemicals have a "skin" notation to indicate that the substance may be appreciably absorbed through direct contact of the material or its vapor with the skin and mucous membranes.

It is important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these occupational health exposure criteria. A small percentage may experience adverse health effects because of individual susceptibility, preexisting medical conditions, previous exposures, or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, or with medications or personal habits of

the worker (such as smoking) to produce health effects even if the occupational exposures are controlled to the limit set by the evaluation criterion. These combined effects are often not considered by the chemical-specific evaluation criteria. Furthermore, many substances are appreciably absorbed by direct contact with the skin and thus potentially increase the overall exposure and biologic response beyond that expected from inhalation alone. Finally, evaluation criteria may change over time as new information on the toxic effects of an agent become available. Because of these reasons, it is prudent for an employer to maintain worker exposures well below established occupational health criteria.

## Asphalt Fumes (Petroleum)

Asphalt, produced from refining crude petroleum, is commercially valuable for pavement construction because of its adhesive properties, flexibility, durability, water and acid resistance, and its ability to form strong cohesive mixtures with mineral aggregates. Asphalt pavement is the major paving product in commercial use and accounts for 85% of the total asphalt usage (and over 90% of the roadway paving) in the United States [AI 1990]. About 4,000 HMA facilities and 7,000 paving contractors employ nearly 300,000 workers in the United States [AI 1990].

The specific chemical content of asphalt, a brown or black solid or viscous liquid at room temperature, is difficult to characterize because it is extremely complex and variable. In general, asphalt primarily contains high molecular weight cyclic hydrocarbon compounds as well as saturated organics. The chemical composition and physical properties of the asphalt products are influenced by the original crude petroleum and the manufacturing processes. The basic chemical components of asphalt include paraffinic, naphthenic, cyclic, and aromatic hydrocarbons as well as heteroatomic molecules containing sulfur, oxygen, and nitrogen [AI 1990].

Petroleum based asphalt and coal tar pitch are often considered to be equivalent materials because of

their similar physical appearance and construction applications. However, these materials are quite different chemically as a result of raw material origin and manufacturing processes. Approximately 80% of the carbon in coal tar is associated with the aromatic ring structures, whereas less than 40% of the carbon in asphalt is present in aromatic rings [Puzinauskas and Corbett 1978]. Furthermore, analysis by nuclear magnetic resonance indicated that an asphalt fume condensate was <1% aromatic and >99% aliphatic, whereas a coal tar pitch condensate was >90% aromatic [Niemeier et al. 1988]. Coal tar has a greater reported carcinogenic activity than asphalt and is considered an occupational carcinogen by NIOSH [1992] and ACGIH [1996].

In a 1977 criteria document, NIOSH established a REL of 5 mg/m<sup>3</sup> (as a 15-minute ceiling limit) for asphalt fumes, measured as TP. This level was intended to protect against acute effects, including irritation of the serous membranes of the conjunctivae and the mucous membranes of the respiratory tract [NIOSH 1977a]. Asphalt fumes can be absorbed through the lungs or the skin. Hansen [1991] and Maizlish et al. [1988] indicated that nonmalignant lung diseases such as bronchitis, emphysema, and asthma were also among the toxic effects of exposure to asphalt fumes. Norseth et al. [1991] reported that during road repair and construction, three groups of asphalt workers experienced abnormal fatigue, reduced appetite, eye irritation, and laryngeal/pharyngeal irritation.

Since publication of the criteria document [NIOSH 1977a], data have become available indicating that exposure to roofing asphalt fume condensates, raw roofing asphalt, and asphalt-based paints may pose a risk of cancer to workers occupationally exposed. In 1988, NIOSH recommended that asphalt fumes be considered a potential occupational carcinogen [NIOSH 1988]. This recommendation was based on information presented in the 1977 criteria document [NIOSH 1977a] and a study by Niemeier et al. [1988] showing that exposure to condensates of asphalt fumes caused skin tumors in mice. Several epidemiologic studies concerning workers exposed

to asphalt fumes have indicated a potential excess in mortality from cancer [Hansen 1989a,b, 1991; Maizlish et al. 1988; Engholm et al. 1991; Wilson 1984; Bender et al. 1989; Mommsen et al. 1983; Risch et al. 1988; Bonassi et al. 1989].

Currently there is no OSHA PEL for asphalt fume. In 1992, OSHA published a proposed rule for asphalt fumes that included a PEL of 5 mg/m<sup>3</sup> (TP) for general industry as well as for the maritime, construction, and agricultural industries [OSHA 1992]. OSHA is presently reviewing public comments. The current ACGIH TLV<sup>®</sup> for asphalt fumes is 5 mg/m<sup>3</sup> as an 8-hour TWA [ACGIH 1996]. This TLV was recommended to "maintain good housekeeping conditions and reduce the risk of possible carcinogenicity" [ACGIH 1992].

Table 3 summarizes the toxicity and exposure criteria information for asphalt fume and the other contaminants evaluated during this study, including TP, respirable particulate, benzene soluble particulate fraction, PACs, elemental carbon, and selected organic solvents.

## INDUSTRIAL HYGIENE RESULTS

### Weather

A daily description of the weather is extremely important since the outdoor conditions directly impact the construction process and air sampling results. Table 4 summarizes the weather data recorded for each survey day. The temperatures on all four asphalt paving days were very hot, ranging from 32°C to 41°C (89 to 105°F).

Wind speed and direction are particularly important factors that may influence the air sampling results. As shown in Table 4, the wind velocity was somewhat similar during all four paving days that were surveyed. Wind direction, however, did vary between conventional and CRM asphalt paving periods. During conventional asphalt paving on

August 22–23, the wind was from the north and east and the wind speed typically ranged from 3 to 10 miles per hour. In contrast, the wind direction during CRM asphalt paving on July 13–14 was from the south and west, with a typical wind speed ranging from 2 to 5 miles per hour. Occasionally some of the paving crew appeared to be downwind from the asphalt fume emissions, including the traffic controller, paver operator, screed operator, and laborers.

### Process Information

Although this paving operation was very similar to ones previously evaluated by NIOSH, several potentially important differences did exist. For example, NIOSH investigators were not aware of the use of recycled asphalt pavement (RAP) until August 1995 (after one-half of the field investigative work had already been completed). Because the residual asphalt cement (AC) in the RAP replaces a portion of the virgin AC, the combined AC will have somewhat different characteristics. The industrial hygiene and medical implications from the use of RAP on this NIOSH study are not known.

When reviewing these industrial hygiene and medical results, it is also important to note that the CRM asphalt paving operations were surveyed *before* the conventional asphalt paving, in contrast to three previous asphalt paving studies conducted by NIOSH. Given the one month interval between the CRM asphalt paving and the conventional asphalt paving, the order should not have affected the environmental or medical results since the latter assessed only acute effects.

Finally, the HMA plant and paving company had not worked with CRM asphalt before this survey. This lack of experience may have partially accounted for the inability of the HMA plant to provide CRM asphalt in sufficient quantities to the paving crew on July 13–14, often resulting in delays of 20 to 40 minutes between asphalt delivery trucks. These frequent breaks for the paving crew (while awaiting another dump truck) continued for the most of each work day on July 13–14, possibly reducing both



exposures and acute symptoms. These delays also affected the average production rate (the number of tons of asphalt paved per hour). During conventional asphalt paving, the average production ranged from approximately 180 to 290 metric tons per hour. In contrast, during the CRM asphalt paving phase the production rates were much lower, ranging from approximately 100 to 160 metric tons per hour.

## Area Air Samples

### **Total Particulate and Respirable Particulate**

Tables 5 and 6 provide the results for the total and respirable particulate concentrations, respectively. All of the TP concentrations were well below the NIOSH REL for asphalt fume of 5 mg/m<sup>3</sup>. Total particulate concentrations at emission locations ranged from 0.09 to 0.25 mg/m<sup>3</sup> and from 0.2 to 1.2 mg/m<sup>3</sup>, for conventional and CRM asphalt paving, respectively. The highest TP concentrations for both asphalt mixes were generally observed above the screed auger. The TP background concentrations measured during this survey ranged from not detected (<0.02 mg/m<sup>3</sup>) to 0.16 mg/m<sup>3</sup>.

The highest respirable particulate concentration (0.58 mg/m<sup>3</sup>) was obtained over the screed during CRM asphalt paving. All of the remaining respirable particulate concentrations collected near asphalt fume emission areas ranged from 0.03 to 0.51 mg/m<sup>3</sup>. All of the background respirable particulate concentrations were either not detected (<0.03 mg/m<sup>3</sup>) or 0.14 mg/m<sup>3</sup>.

### **Benzene Soluble Particulate Fraction**

As summarized in Table 7, the highest BSF concentrations were measured above the screed auger during CRM asphalt paving. Benzene soluble particulate concentrations ranged from ND (<0.08 mg/m<sup>3</sup>) to trace amounts (concentrations

between 0.08 and 0.26 mg/m<sup>3</sup>) during conventional paving. During CRM asphalt paving the BSF concentrations ranged from 0.06 to 0.98 mg/m<sup>3</sup>, with the highest BSF concentrations being measured on July 14 (the second day of CRM asphalt paving sampling). Presently, there are no occupational exposure criteria from NIOSH or OSHA for the benzene soluble particulate fraction of asphalt fume.

### **Polycyclic Aromatic Compounds (PACs), Sulfur-containing Compounds, and Benzothiazole**

Two asphalt fume source samples from this study were analyzed by high pressure liquid chromatography (HPLC). The chromatograms obtained from these samples demonstrated the typical pattern associated with asphalt fume (a large number of compounds which have similar chromatographic elution times). This chromatographic pattern prevents quantitation of individual PAHs. Hence, NIOSH method 5506 was modified to quantitate total PACs, as a class, via a flow injection technique with spectrofluorometric detection using emission wavelengths of 370 and 400 nanometers (nm). The 370 nm emission wavelength provides greater sensitivity to 2–3 ring PACs and the 400 nm wavelength is more sensitive to 4–7 ring PACs.

Table 8 summarizes the total PAC area concentrations collected at emission and background locations. The concentration for the total PAC<sub>370</sub> at emission sources ranged from 14 to 49 micrograms per cubic meter (µg/m<sup>3</sup>) for conventional and from 41 to 216 µg/m<sup>3</sup> for CRM asphalts. The total PAC<sub>400</sub> concentrations from these same samples ranged from 1.9 to 6.0 and from 6.1 to 35 µg/m<sup>3</sup> for conventional and CRM asphalt paving, respectively. In every sample the PAC<sub>370</sub> concentrations were greater than the PAC<sub>400</sub> concentrations implying that the 2–3 ring PACs may be more abundant. The smaller ring number PACs are believed to be associated with more irritative effects, whereas more concern exists for suspect carcinogenicity of the 4–7 ring PACs. Occupational exposure criteria for total PACs, as a

class, are presently unavailable from either NIOSH, OSHA, or ACGIH.

Table 8 also presents the sulfur compounds and benzothiazole concentrations obtained from hexane extracts of PAC samples which were analyzed by gas chromatography with sulfur chemiluminescence detection. Benzothiazole, an additive used in tire manufacturing, was generally not detected ( $<1.2 \mu\text{g}/\text{m}^3$ ) on conventional asphalt projects. Benzothiazole concentrations during CRM asphalt paving, however, were much higher, ranging from 31 to  $127 \mu\text{g}/\text{m}^3$  at emission locations. This implies that the CRM asphalt formulation appears to be more important for generating benzothiazole. The background benzothiazole levels on all asphalt paving days were generally below the minimum detectable concentration ( $<1.2 \mu\text{g}/\text{m}^3$ ). The highest benzothiazole concentrations were measured over the screed auger area of the paver on both CRM asphalt paving days.

Overall, the highest concentration of sulfur compounds ( $792 \mu\text{g}/\text{m}^3$ ) was measured at the screed auger area of the paver hopper during CRM asphalt paving. For the remaining samples, the highest concentrations detected for sulfur compounds during conventional and CRM asphalt paving were 105 and  $296 \mu\text{g}/\text{m}^3$ , respectively. Concentrations of sulfur compounds were generally higher at every emission location during CRM asphalt paving compared to conventional asphalt. On three of the four paving days, the background concentrations of sulfur compounds were not detected ( $<1.5 \mu\text{g}/\text{m}^3$ ). However, on August 22, the measured background sulfur concentration was  $11 \mu\text{g}/\text{m}^3$ . The reason for this higher concentration is unknown.

### ***Elemental and Organic Carbon***

Elemental and organic carbon samples collected during conventional asphalt paving on August 22–23, 1995, were lost during analysis and no results can be reported for this period. The remaining sample results, provided in Table 9, show that all of the EC concentrations collected on the paver vehicle during CRM asphalt paving were above the

background concentrations. However, the EC:TC ratio ranged from 3.6 to 6% at the paver hopper (which is adjacent to the paver engine) and from 1.4 to 1.6% above the screed. Since diesel exhaust has been reported to contain EC levels between 60 to 80% of the TC [Blade et al. 1989], the much lower EC:TC ratios measured in this survey imply that diesel exhaust was not substantially contributing to the air sampling results. Since the same paving equipment was also used for the conventional asphalt paving, it is assumed that similarly low EC:TC ratios would also exist.

### ***Volatile Organic Compounds (VOCs) and Elements***

Table 10 summarizes the predominant VOC concentrations detected during both the conventional asphalt and CRM asphalt paving periods. The qualitative GC/MS analysis identified over 50 VOCs. However, only the most significant peaks (benzene, toluene, xylene, methyl isobutyl ketone [MIBK], and total hydrocarbons) were quantitatively analyzed by GC/FID. The quantities of VOCs detected at emission sources were orders of magnitude below their respective occupational exposure criteria published by NIOSH, OSHA, or ACGIH. The highest VOC concentrations were measured for MIBK, ranging from 0.12 to 0.92 ppm during CRM asphalt paving. Trace amounts of xylene and benzene were detected this same period. Benzene, toluene, xylene, and MIBK were not detected ( $<0.02$  ppm) during conventional asphalt paving.

Extremely low or trace concentrations were observed for aluminum, calcium, iron, magnesium, manganese, and titanium. All other elemental metals were not detected.

### ***Hydrogen Sulfide (H<sub>2</sub>S), Sulfur Dioxide (SO<sub>2</sub>), Carbon Monoxide (CO), and Ozone (O<sub>3</sub>)***

Direct reading instrumentation was used to measure H<sub>2</sub>S, SO<sub>2</sub>, CO, and O<sub>3</sub> at the paving site. All of these



compounds were present in very low concentrations and were well below their respective occupational exposure limits. Hydrogen sulfide and SO<sub>2</sub> were not detected near asphalt fume emission sources. Carbon monoxide concentrations were approximately 2–3 ppm at the paving site, ranging up to approximately 7–9 ppm near the asphalt delivery trucks. The NIOSH REL for CO is an 8-hour TWA of 35 ppm. Background O<sub>3</sub> concentrations were typically <0.01 ppm.

### **Comparison of Sampling Methods for Measuring TP and BSF**

Appendix C compares the results obtained from side-by-side area air samples collected for TP and BSF. NIOSH Sampling Method No. 0500 (TP collected on a tared polyvinyl chloride [PVC] filter, followed by gravimetric analysis) and OSHA Analytical Method No. 58 (TP collected on an unweighed Zefluor filter, then extracted with benzene and the benzene soluble fraction is gravimetrically analyzed) were the primary sampling and analytical techniques used in this evaluation. A newly developed sampling method, consisting of a *tared* Zefluor filter which is gravimetrically analyzed (for TP), followed by analysis for BSF by OSHA Analytical Method No. 58, was also used. The presumed advantage to this method is that both TP and the BSF are obtained from a single filter sample. Area air samples were collected at the paver hopper, the screed, and at highway background locations on all four asphalt paving days using both sampling methods.

Excluding the TP concentrations measured at the highway background locations (which were typically very low), TP concentrations around the paver ranged from 0.09 to 1.2 mg/m<sup>3</sup> (average = 0.48 mg/m<sup>3</sup>) for samples collected on tared PVC filters and gravimetrically analyzed according to NIOSH Sampling Method No. 0500. In side-by-side samples, TP concentrations collected on tared Zefluor filters and gravimetrically analyzed were similar, ranging from not detected

(<0.01 mg/m<sup>3</sup>) to 1.3 mg/m<sup>3</sup> (average = 0.51 mg/m<sup>3</sup>). The BSF concentrations collected from around the paver ranged from ND (<0.08 mg/m<sup>3</sup>) to 0.98 mg/m<sup>3</sup> (average = 0.28 mg/m<sup>3</sup>) using OSHA Analytical Method No. 58; using the new sampling method (tared Zefluor filters), the BSF concentrations ranged from not detected (<0.08 mg/m<sup>3</sup>) to 1.5 mg/m<sup>3</sup> (average = 0.43 mg/m<sup>3</sup>). Using a non-parametric statistical test for paired data, the observed difference in the TP concentrations measured with these two methods was not statistically significant ( $p \leq 0.05$ , two-tailed test). The observed difference in the BSF concentrations, however, was statistically significant. Since this was the first use of a new sampling method, the difference in the results and the implications for assessing worker exposure are unknown at this time. All of the area and PBZ sample results for TP and BSP shown in Tables 5, 7, and 11 were obtained using NIOSH Sampling Method No. 0500 and OSHA Method No. 58.

### **Personal Breathing Zone Air Samples**

Table 11 presents the PBZ monitoring results for TP collected during conventional and CRM paving operations. All of the PBZ exposures were well below the criteria of 5 mg/m<sup>3</sup> currently proposed by NIOSH. The TWA PBZ exposure to TP ranged from not detected (<0.02 mg/m<sup>3</sup>) to 0.3 mg/m<sup>3</sup> and from not detected (<0.02 mg/m<sup>3</sup>) to 0.67 mg/m<sup>3</sup> during conventional and CRM asphalt paving, respectively. The highest TP PBZ exposures were measured on laborers working on the CRM asphalt paving days. As may be expected, the PBZ TP exposures for the paver and screed operators (since they were closest to the delivery trucks and the active asphalt paving) were typically higher than the concentrations measured on the roller operators (regardless of the asphalt composition). Although TP concentrations were generally higher during CRM asphalt paving than during conventional asphalt paving, a conclusion regarding this difference cannot be easily determined due to the limited number of PBZ samples.

As shown in Table 12, PBZ concentrations of PACs (at both 370 and 400 emission nanometers), benzothiazole, and sulfur compounds were higher during CRM asphalt paving than during conventional asphalt paving. The PBZ concentrations of PAC<sub>370</sub> during conventional and CRM asphalt paving ranged up to 2.8 and 8.7  $\mu\text{g}/\text{m}^3$ , respectively. Concentrations of benzothiazole, detected only during CRM asphalt paving, ranged up to 58  $\mu\text{g}/\text{m}^3$ .

## MEDICAL RESULTS

The ten non-pavers recruited for the health assessment included one crew foreman, two heavy equipment operators, and seven laborers. One non-paver (a heavy equipment operator) was excluded from analysis of the medical data due to unreliable and inconsistent responses during the health assessment. This individual reported numerous symptoms of varying severity during the last two survey days. These symptoms were judged by the NIOSH investigator to be inconsistent with the worker's appearance and behavior. Of the remaining nine non-pavers, two (a laborer and a heavy equipment operator) participated in the study for all four days, two (both laborers) participated only on days 1 and 2, and five (all laborers) participated only on days 3 and 4.

The nine pavers recruited for the health assessment included one paver operator, two screed operators, two roller operators, two rakers/laborers, one state highway inspector, and one paving foreman. Two pavers (a raker/laborer and the paving foreman) were excluded from analysis of the medical data due to lack of exposure to the paving operation on the first two survey days. Of the seven remaining pavers, five fully participated in the study for all four days. Two declined to fully participate (one declined to participate on day 3, and both participated only partially on day 4, answering all symptom

questionnaires but performing PEFR testing only twice).

All results below pertain only to the nine non-pavers and seven pavers for whom data were analyzed. All nine of the non-pavers were male, with an average age of 39 years (range 22–55 years). All seven pavers were male, with an average age of 44 years (range 32–59 years). Three of the non-pavers currently smoked cigarettes (all smoked during work), four never smoked, and two were former smokers. Three of the pavers currently smoked cigarettes (all smoked during work), three never smoked, and one was a former smoker.

The number of acute symptom questionnaires completed (i.e., the number of opportunities a worker had to report a health symptom) varied somewhat between survey days and among the non-pavers and pavers (Table 13). For the non-pavers, a maximum of 20 (four workers times five questionnaires/day) questionnaires could have been completed during each of the first two survey days (days 1 and 2) and a maximum of 35 (seven workers times five questionnaires/day) questionnaires could have been completed during each of the last two survey days (days 3 and 4). For each survey day, a maximum of 35 (seven workers times five questionnaires/day) questionnaires could have been completed for the pavers. The non-pavers completed 39 (98%) questionnaires on the first and second survey days and 68 (97%) on the third and fourth survey days. The pavers completed all 70 (100%) questionnaires during the CRM asphalt paving period as compared to 56 (80%) questionnaires during the conventional asphalt paving period.

Responses to the acute health questionnaires were evaluated for symptoms potentially associated with worker tasks and exposures. A worker could report seven different types of symptoms during each survey time (including eye, nose, throat, and skin irritation, cough, shortness of breath, and wheezing); each such symptom report will be referred to as a "symptom occurrence." Thus, if a worker completed all five questionnaires and reported all seven symptoms each time, he would have 35 symptom

occurrences for that survey day.

Table 14 shows the number of workers reporting a health symptom at any time during a survey day. Also shown is the number of symptom occurrences reported during the survey day. Among non-pavers, all three symptom occurrences (one occurrence of shortness of breath and two occurrences of eye irritation) were reported by one worker on two survey days (days 1 and 3). Among pavers, three workers reported nine symptom occurrences on the first survey day and two reported ten occurrences on the second survey day (CRM asphalt paving period). In comparison, two pavers reported two symptom occurrences on the third survey day and three reported four occurrences on the fourth survey day (conventional asphalt paving period). Among pavers, the most frequently reported symptoms (as a percentage of occurrences on all four days) were cough (40%), throat irritation (36%), and eye, nasal, and skin irritation (each 8%). Nineteen of the 25 (76%) symptoms reported by pavers occurred during the CRM asphalt paving period. Of note, one paver reported 72% (18/25) of the symptom occurrences, with 83% (15/18) of these reports occurring during the CRM asphalt paving period. Eighty-four percent (21/25) of the pavers' symptoms were reported during ongoing or recent exposure to asphalt fumes. Ninety-two percent (23/25) of the symptoms reported by the pavers were rated as "mild" in severity (the choices were "mild," "moderate," or "severe"). The three symptom occurrences reported by non-pavers (one during the CRM asphalt paving period and two during the conventional asphalt paving period) were all rated as "mild" in severity.

Because of differences in the number of completed questionnaires, the *number* of symptom occurrences may not be the best measure for comparing health effects between CRM and conventional asphalt paving exposures. A more appropriate measure is the *rate* of symptom occurrences per completed questionnaire (defined as the *number of symptom occurrences* divided by the *number of completed questionnaires*). The rates of reported symptom occurrences among pavers by survey day are presented in Table 15. Although pavers completed

about 25% more acute symptom questionnaires during the CRM asphalt paving period, this does not appear to account for the observed change in the number of reported symptom occurrences during the CRM asphalt paving period. The symptom reporting rate increased from 0.11 symptoms per completed questionnaire during the conventional asphalt paving period to 0.27 symptoms per completed questionnaire during the CRM asphalt paving period, a 2.5-fold increase.

The number of hours the road crew performed paving operations, and thus were potentially exposed to asphalt fumes, varied between survey days. Each paver estimated his or her own exposure time to the paving operation (typically in 15-minute increments) and this information was collected with each acute symptom questionnaire. Table 16 shows each paver's estimated exposure time to asphalt paving for each survey day. The average estimated hours of exposure to asphalt paving was higher during the conventional asphalt paving period. Workers had a combined average of 8.2 hours of exposure/day to the paving operation during the conventional asphalt paving period, compared to a combined average exposure of 6.5 hours/day during the CRM asphalt paving period. All non-pavers denied any exposure to asphalt paving at any time during the survey period.

The *rate* of reported symptom occurrences per hour of estimated exposure to asphalt fume (defined as the *number of symptom occurrences* divided by the *number of hours of estimated exposure*) was calculated for the pavers for each survey day (Table 17). The rate of symptom occurrences per hour of exposure among pavers was approximately 3.5-fold higher during the CRM asphalt paving period (0.21 symptom occurrences per hour of exposure) as compared to the conventional asphalt paving period (0.06 symptom occurrences per hour of exposure).

While symptoms of cough and shortness of breath were reported during the survey period, none of the PEFR measurements revealed any workers with significant bronchial lability (i.e., difference between a day's minimum and maximum PEFR exceeding

20% of that day's maximum PEFR) on any survey day.

## DISCUSSION

### Weather

The weather, especially wind conditions, could affect air sampling measurements obtained outdoors during this construction project. Based on observations of the paver and the movement of the asphalt plume, it appears that the wind could impact the area air samples collected near the paver hopper more than those collected above the screed auger. (The paver hopper was more open and emissions were more prone to effects from wind speed and direction than at the more enclosed screed auger area.) Therefore, the screed sample results may be more useful than the hopper sample results for comparison between conventional and CRM asphalt paving.

### Process Information

Perhaps the most significant difference between conventional and CRM asphalt paving construction projects during this survey was the production rate. During conventional asphalt paving, the average production ranged from approximately 180 to 290 metric tons per hour. In contrast, during the CRM asphalt paving phase, the production rates were much lower, ranging from approximately 100 to 160 metric tons per hour. One explanation for the difference in these production rates was the difficulty the HMA plant encountered on July 13 and 14 in consistently blending sufficient quantities of the CRM asphalt. The paving crew would occasionally wait up to 30 minutes between delivery trucks.

Another unanticipated difference between the conventional and CRM asphalt paving periods on this project was the use of recycled asphalt pavement (RAP) in the conventional asphalt mix. Although the use of RAP was completely acceptable in this paving contract, the NIOSH investigators were not aware of its use until August 1995. Because the residual AC

in the RAP replaces a portion of the virgin AC, the combined AC will have somewhat different characteristics. The industrial hygiene and medical implications from the use of RAP on this NIOSH study are not known.

### Air Sampling

The current NIOSH REL for asphalt fume is 5 mg/m<sup>3</sup>, measured as TP. All of the PBZ samples, and all but one of the area samples, collected adjacent to emission sources had concentrations below this limit. However, exposure criteria are presently unavailable for several groups of compounds (such as total PACs, sulfur compounds, and benzothiazole) which are present in asphalt fume. Concentrations of other compounds (i.e., toluene, xylene, MIBK, petroleum distillates, etc.) that were detected above the screed were also well below any existing occupational exposure limit. Benzene was detected in area samples collected near the hopper and screed; NIOSH considers benzene to be an occupational carcinogen and recommends that exposure be reduced to the lowest feasible level.

Jobs that cause the worker to be in closer proximity to HMA for prolonged durations (and thus have greater exposure to asphalt fume) were also jobs that were less likely involved in activities that generated dust. In this regard the paver, screed operators, and laborers' PBZ exposures probably represents the highest asphalt fume exposure among workers on the paving crew. For these more highly exposed workers, the TP PBZ exposures during the CRM asphalt paving period were slightly higher than the conventional asphalt paving period (0.08 to 0.67 mg/m<sup>3</sup> versus <0.02 to 0.3 mg/m<sup>3</sup>, respectively).

Table 18 contains the results from the area air samples, arranged by location. Although there were many inconsistent factors that could affect results, the following descriptive observations are presented:

P In general, the TP, respirable particulate, and BSF concentrations were higher during CRM asphalt paving than during conventional asphalt paving, despite the higher average production rates during

conventional paving.

P Two detector emission wavelengths were used to provide greater sensitivity either to 2–3 ring PACs (370 nanometers [nm]) or to 4+ ring PACs (400 nm). Greater PAC concentrations were detected using the 370 nm wavelength, implying that the 2–3 ring PACs may be more abundant. The smaller ring number PACs are believed to be associated with more irritative effects, whereas more concern exists for suspect carcinogenicity of the 4–7 ring PACs. Occupational exposure criteria for total PACs, as a class, are presently unavailable from either NIOSH, OSHA, or ACGIH.

P Total PAC concentrations above the hopper and screed were much higher on CRM asphalt paving days than on conventional paving days. Furthermore, the CRM asphalt paving appeared to generate higher concentrations of sulfur compounds. In addition, benzothiazole was detected above background concentrations only during CRM asphalt paving.

## Medical

The results of the acute symptom survey revealed a 2.5–fold increase in the *rate* of symptom occurrences *per completed questionnaire*, and a 3.5–fold increase in the *rate* of symptom occurrences *per self-reported hour of asphalt paving exposure* during the CRM asphalt paving period as compared to the conventional asphalt paving period. The observed increase in symptom occurrences was primarily due to increased reporting of mild throat irritation and coughing among pavers during the CRM asphalt paving period.

Evaluation of acute symptoms in combination with peak flow testing was performed to determine whether acute irritant effects of the airways (as measured by symptom reporting) were associated with intermittent or reversible bronchospastic responses. While acute irritant symptoms, including lower airway symptoms, were reported by workers in association with work site exposures, none of the reported symptoms were accompanied by significant

bronchial lability. The inability to detect an association, if truly present, between reported symptoms and/or exposures and PEFV results at this study site may be due to the small number of workers tested and/or variability between worker exposures and individual responses to those exposures. Also, the two-hour PEFV testing interval may lack sufficient sensitivity to detect transient bronchospastic effects. Evaluation of the relationship between reported symptoms, bronchoreactivity (if any), and any environmental measurements indicative of workers' asphalt fume exposure will be conducted as additional data become available from other study sites. Upon completion of the entire study, a composite report providing an evaluation and analysis of data taken from each of the individual reports will be issued.

## CONCLUSIONS

Results presented here apply only to this survey and cannot be generalized to indicate the exposures or health effects associated with CRM asphalt paving. This study showed that asphalt fume emissions, as well as other exposures, were below current NIOSH RELs or other relevant exposure limits (for those substances that have them). Higher concentrations of TP, respirable particulate, BSF, PACs, and other sulfur-containing compounds (except benzothiazole) were measured over the screed during the CRM asphalt paving periods than during conventional asphalt paving periods. Benzothiazole (above background concentrations) was detected only during CRM asphalt paving periods. Acute symptoms were reported by workers in association with asphalt paving exposures, with higher symptom prevalences associated with CRM asphalt paving. Although the higher symptom rates associated with CRM asphalt paving appear consistent with the higher area air concentrations measured during the CRM asphalt paving periods, the limited number of both area and PBZ air samples obtained from this one evaluation makes further interpretation of this association

difficult. Also, the extent, if any, to which our exposure and health findings may have been influenced by the presence of recycled asphalt pavement during conventional paving is unknown. Presently, NIOSH investigators feel it is premature to draw definitive conclusions from this single site evaluation. The findings from this evaluation are based on a very small sample size and may reflect production and weather conditions specific to this site. Additional site evaluations may increase our ability to understand and interpret observations made at this site and should lead to more definitive conclusions.

## RECOMMENDATIONS

The following interim recommendations are based on observations made during the survey and are intended to help ensure the safety and health of paving crew workers. These recommendations stem from our present understanding of the workers' occupational exposures and potential health effects associated with these exposures. Any additional recommendations specifically concerning asphalt fume exposure will be included in a final composite report.

1. To minimize asphalt fume generation, the hot mix should be applied at the lowest temperature possible that can maintain quality control

specifications.

2. To avoid contamination and possible ingestion of potentially harmful substances, workers should be prohibited from consuming food and beverages and from using tobacco products in close proximity to asphalt fume emissions.

3. Workers should be provided with adequate washing facilities for use prior to eating and leaving the work site.

4. To reduce potential contamination of workers' cars and homes, workers should be encouraged to change clothing prior to leaving the worksite and should be provided with adequate facilities for changing.

5. All workers should wear protective clothing or appropriate sunscreen to shield exposed skin surfaces from the harmful ultraviolet component of sunlight.

6. Over the course of this survey workers were observed performing a number of job tasks which could potentially lead to musculoskeletal injury. Employees performing manual lifting and shoveling should be taught appropriate lifting techniques and be provided with the appropriate equipment to minimize musculoskeletal strain.



## ABBREVIATIONS AND TERMS

ACGIH	American Conference of Governmental Industrial Hygienists	IH	Industrial hygiene
BSF	Benzene soluble (particulate) fraction	ISTEA	Intermodal Surface Transportation Efficiency Act
C	Ceiling, an exposure that shall not be exceeded during any part of the workday	LC	Liquid chromatography
CFR	Code of Federal Regulations	LOD	Limit of detection (analytical method)
cm <sup>2</sup>	Square centimeters	LOQ	Limit of quantitation (analytical method)
CO	Carbon monoxide	Lpm	Liters per minute
Control	A person working in road construction but not exposed to hot asphalt fume.	MCE	Mixed cellulose–ester filter
CRM	Crumb rubber modified	MDC	Minimum <i>detectable</i> concentration (the smallest amount of a material which can be reliably detected). The MDC is calculated by dividing the analytical LOD by a representative air volume.
DOT	Department of Transportation	mg	Milligrams
EC	Elemental carbon	mg/m <sup>3</sup>	Milligrams per cubic meter of air
EPA	Environmental Protection Agency	MIBK	Methyl isobutyl ketone
FHWA	Federal Highway Administration	mL	Milliliter
FID	Flame ionization detector	mm	Millimeter
GC–MS	Gas chromatography–Mass Spectrometry	MQC	Minimum <i>quantifiable</i> concentration (the smallest amount of a material which can be reliably measured). The MQC is calculated by dividing the analytical LOQ by a representative air volume.
H <sub>2</sub> S	Hydrogen sulfide	ND	Not detected
HHE	Health hazard evaluation	NIOSH	National Institute for Occupational Safety and Health
HMA	Hot mix asphalt		
IARC	International Agency for Research on Cancer		
ICP–AES	Inductively coupled (argon) plasma–atomic emission spectroscopy		

nm	Nanometer	TLV <sup>®</sup>	Threshold limit value (ACGIH exposure criteria)
OC	Organic carbon	TWA	Time-weighted average
OSHA	U.S. Occupational Safety and Health Administration	VOCs	Volatile organic compounds
PAC <sub>370</sub>	PACs monitored at an emission wavelength of 370 nanometers (representative of 2-ring and 3-ring compounds)	WBGT	Wet bulb globe temperature
PAC <sub>400</sub>	PACs monitored at an emission wavelength of 400 nanometers (representative of 4-ring and higher compounds)	°C & °F	Degrees Celsius and Degrees Fahrenheit
PACs	Polycyclic aromatic compounds	µg	Microgram (10 <sup>-6</sup> ), a unit of weight
PAHs	Polynuclear aromatic hydrocarbons	µg/m <sup>3</sup>	Micrograms of contaminant per cubic meter of air (a unit of concentration)
PBZ	Personal breathing-zone air sample		
PEFR	Peak expiratory flow rate		
PEL	Permissible exposure limit (OSHA)		
ppm	Parts (of a contaminant) per million parts of air		
REL	Recommended exposure limit (NIOSH exposure criteria)		
RP	Respirable particulate		
SCLD	Sulfur chemiluminescent detector		
Screed	During road paving, the screed levels the hot-mix asphalt to the desired thickness and slope as the paving vehicle moves forward		
SO <sub>2</sub>	Sulfur dioxide		
STEL	Short-term exposure limit		
TC	Total carbon (elemental + organic)		



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# APPENDIX A

## MODIFIED ANALYTICAL METHOD FOR POLYCYCLIC AROMATIC COMPOUNDS

Larry Jaycox, Charles Neumeister, and Larry Olsen

Historically, attempts to characterize asphalt fume have focused on the analysis of 16 standard unsubstituted polynuclear aromatic hydrocarbons (parent PAHs). This approach has been successful in most of the other matrices where PAH exposure occurs; however, asphalt fume is composed of a multitude of aliphatic and alkylated polycyclic aromatic compounds (PACs) so complex that the mixture cannot be separated into discrete compounds. The analytical results obtained from analyzing asphalt fume samples by simply monitoring the 16 parent PAHs typically does not yield useful information regarding worker exposure.

Individual PACs typically are not quantifiable from asphalt fume if the current NIOSH liquid chromatography (LC) and gas chromatography (GC) methods (NIOSH methods 5506 and 5515) for PACs are used. This is due to the enormous number of substituted PACs in asphalt fume that are present in minute quantities which create signal interference from compounds that chromatographically co-elute at the same retention time. This has been previously shown in conventional asphalt fume studies when only the standard 16 unsubstituted PACs were evaluated.

Furthermore, the current method for detecting PACs does not evaluate the asphalt fumes for the compounds believed to be the most likely human health hazards. The health hazards associated with asphalt fume exposure are usually attributed to PACs that contain three to seven annulated rings with side chains of one to two carbons in length (with a maximum of four saturated carbons), or to PACs containing nitrogen, oxygen, and sulfur. For these reasons, a new method has been developed to separate the asphalt fume samples into aliphatic, aromatic, and polar fractions.

Since the published NIOSH methods do not account for all of these different compound types, the current methods were modified to provide a better indication of the total PAC content of the asphalt fumes. A new liquid chromatographic method was developed to give a better indication of the total PAC content in asphalt fume. This was achieved by adapting existing methods, reported in the literature, to initially remove the saturated compounds and the highly polar organic compounds. The remaining PACs can then be analyzed by LC with fluorescence detection. This modification should not only allow for the detection of the standard 16 PACs, that are usually analyzed, but should also allow measurement of the total PAC content present in each sample (i.e. sum of the peak areas). The total PAC content in the sample can then be compared to a PAH reference standard mixture to determine which fume samples have the most PACs. The total PAC content of the crumb rubber modified (CRM) asphalt fume can be compared to the total PAC content of the conventional asphalt collected from each sample location.

A commercially available standard mixture of 16 PACs was used in a recovery study to show that these compounds are not lost during sample preparation and that the remaining materials can be analyzed. Asphalt fume collected from an earlier pilot investigation has been used to test the possible methods. The sample preparation used solid phase extraction columns and solvent extraction steps. The material remaining after the sample preparation (PACs) was analyzed by means of a reversed-phase high performance liquid chromatographic column with fluorescence detection. After this study was successfully accomplished, the asphalt fume samples collected from paving construction sites were analyzed.

The air sampling collection methods for PACs are very similar to those published in NIOSH method 5506, Polynuclear Aromatic Hydrocarbons. The sampling train consisted of 37-mm, 2 µm pore size, Teflon® filter to collect particulate PACs, connected in series with an ORBO 43 sorbent tube to collect volatile or semi-volatile PACs. Air was sampled at a pump flow rate of 2 liters per minute (lpm). Opaque filter cassettes and sorbent tube holders were used to prevent the degradation of PACs by ultraviolet light.

After collection, the asphalt fume sample was extracted from the sampling filter with hexane. The hexane extract was then eluted through a cyano solid phase extraction column. The polar material will be retained on the column, and the aliphatic and the aromatic compounds will elute with hexane. Dimethyl sulfoxide (DMSO) is added to the hexane solution; the aromatic compounds will partition into the DMSO layer while the aliphatics will remain in the hexane layer. Next, the polar compounds are eluted from the column with methanol. The aromatic compounds in the DMSO fraction are analyzed by means of reversed-phase liquid chromatography with fluorescence detection. Since the excitation and emission wavelengths are not the same for all PACs, two sets of excitation and emission wavelengths were utilized. One set of wavelengths is more sensitive for the 2-ring and 3-ring compounds (254 nm excitation, 370 nm emission), and the other set of wavelengths is more sensitive for the 4-ring and higher compounds (254 nm excitation, 400 nm emission). Finally, the total fluorescent response was normalized with a commercially available standard of 16 unsubstituted PAHs.

This methodology was applied to a representative number of CRM and conventional asphalt samples that were obtained from emission locations. The results obtained from this procedure confirmed that the chromatograms were due to widespread signal responses, elapsing over 20 minutes of column retention time indicative of co-elution interference. Upon completion of the chromatography, the samples were analyzed with a flow injection (FI) technique where the LC column was bypassed; an aliquot of the DMSO/asphalt fume extract was injected directly into the fluorescence detection system. The advantage of this modification is that it is a much quicker procedure and the signal response is a single, reproducible peak due to all PAC compounds that fluoresce at the selected wavelength producing a more sensitive and precise signal. The total fluorescent response was also normalized with the same commercially available standard of 16 unsubstituted PAHs that was used in the chromatography methods.

Furthermore, an investigation of the compounds that contain sulfur was conducted. If a significant difference exists between conventional and CRM asphalt, it may be evident in the number and type of sulfur compounds in each asphalt formulation because of the vulcanizing process used during rubber tire production. Preliminary analyses by GC/MS have indicated that the CRM asphalt does contain more sulfur-containing compounds than the conventional asphalt mix. Additionally, higher levels of benzothiazole was present in the CRM asphalt samples. To exploit this potential difference in the asphalt compounds, a sulfur chemiluminescent detector (SCLD) was used in conjunction with a gas chromatograph (GC). This detector is sulfur specific and enables the analysis of sulfur in the low picogram range. The GC/SCLD system was used to analyze hexane extracted sample aliquots prepared from each asphalt fume sample.

# APPENDIX B

## ELEMENTAL CARBON (DIESEL EXHAUST)

5040

C

MW: 12.01

CAS: none

RTECS: none

METHOD: 5040, Issue 1

EVALUATION: PARTIAL

Issue 1: 15 March 1996

OSHA :  
NIOSH: see APPENDIX A  
ACGIH:

PROPERTIES: nonvolatile solid; MP >350 °C

SYNONYMS (related terms): soot, black carbon, diesel emissions, diesel exhaust particles, diesel particulate matter

### SAMPLING

### MEASUREMENT

**SAMPLER:** FILTER  
(quartz fiber, 37-mm; size-selective impactor may be required, see INTERFERENCES)

**FLOW RATE:** 1 to 4 L/min

**VOL-MIN:** 106 L @ 40 µg/m<sup>3</sup>  
**-MAX:** 4300 L (for filter load ~ 20 µg/cm<sup>2</sup>)

**SHIPMENT:** routine

**SAMPLE STABILITY:** stable

**BLANKS:** 2 to 10 field blanks per set

**TECHNIQUE:** EVOLVED GAS ANALYSIS (EGA) by thermal-optical analyzer

**ANALYTE:** elemental carbon (EC)

**FILTER PUNCH SIZE:** 1.54 cm<sup>2</sup>

**CALIBRATION:** methane injection [1]

**RANGE:** 0.76 to 54 µg per filter portion

**ESTIMATED LOD:** 0.2 µg per filter portion

**PRECISION (S<sub>r</sub>):** 0.10 @ 1 µg C,  
0.01 @ 10–72 µg C

### ACCURACY

**RANGE STUDIED:** 4.0 mg/m<sup>3</sup>  
(60-L sample) [1]

**BIAS:** none [1]

**OVERALL PRECISION (S<sub>r</sub>):** see EVALUATION OF METHOD

**ACCURACY:** see EVALUATION OF METHOD

**APPLICABILITY:** The working range is 4.4 to 312 µg/m<sup>3</sup> with a LOD of ~1.3 µg/m<sup>3</sup> for a 960-L air sample collected on a 37-mm filter with a 1.54 cm<sup>2</sup> punch from the sample filter. If a lower LOD is desired, a larger sample volume and 25-mm filter may be used (e.g., a 1920-L sample on 25-mm filter gives an LOD of 0.3 µg/m<sup>3</sup>) [1]. The split between organic-based carbon (OC) and EC may be affected at higher EC loadings (e.g., >30 µg/cm<sup>2</sup> of filter), depending on type and amount of OC present. If pyrolysis correction is not required, an upper limit of ~800 µg/m<sup>3</sup> (90 µg/cm<sup>2</sup>) can be determined, but post-analysis designation of OC-EC split may be necessary [1].

**INTERFERENCES:** As defined by the thermal-optical method, EC is the carbon determined during the second stage of the analysis (after pyrolytic correction). If the sample contains no pyrolyzable material, all the carbon evolved during this stage is considered elemental. Carbonate and cigarette smoke do not interfere. Various EC sources (diesel engines, carbon black, coal dust, and humic acid) may be present [1]. For measurement of diesel-source EC in coal mines, an impactor with submicrometer cutpoint [2,3] must be used to minimize collection of coal dust.

**OTHER METHODS:** Other methods for determination of EC and OC are described in the literature [4].

**REAGENTS:**

1. Aqueous organic carbon solutions (e.g., sucrose), 0.10 to 2.4 mg C per mL solution.
2. Helium, prepurified.
3. Hydrogen, purified.
4. Oxygen (10%) in helium, premixed, purified.
5. Methane (5%) in helium, premixed, purified.

**EQUIPMENT:**

1. Sampler: Quartz fiber filter, precleaned (clean in low temperature asher 2 to 3 h, or muffle furnace at ~ 800 °C), 37-mm, in a 3-piece, 37-mm cassette with support pad (stainless steel or cellulose).
2. Personal sampling pump, 1 to 4 L/min, with flexible tubing.
3. Thermal-optical analyzer, or other analyzer capable of EC speciation (see APPENDIX B).
4. Punch (e.g., cork borer) for removal of filter sample portion.  
NOTE: Portion  $\geq 0.5$  cm<sup>2</sup> with diameter or width of  $\leq 1$  cm is recommended.
5. Syringe, 10- $\mu$ L

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**SPECIAL PRECAUTIONS:** None

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**SAMPLING:**

1. Calibrate each personal sampling pump with a representative sampler in line.  
NOTE: Sampler should be used in open-face configuration.
2. Attach sampler outlet to personal sampling pump with flexible tubing. Remove top piece of cassette.
3. Sample at an accurately known flow rate between 1 and 4 L/min.
4. After sampling, replace top piece of cassette and pack securely for shipment to laboratory.  
NOTE: If the EC in the sample is more difficult to oxidize (e.g., graphite) than typical black carbon (e.g., soot), notify the laboratory of this fact.

**SAMPLE PREPARATION:**

5. Use punch to cut out a representative portion of the sample filter for analysis. Take care not to disturb deposited material and avoid hand contact with sample.

**CALIBRATION AND QUALITY CONTROL:**

6. Perform CH<sub>4</sub> calibration injection at end of each sample analysis.
7. If a particular sample filter deposit appears uneven, take a duplicate portion (step 5) for analysis to check evenness of deposition. Analyze at least one duplicate and others as required to replicate 10% of the samples for sets of up to 50 samples and 5% of the samples over 50.  
NOTE: Precision in duplicate analyses of a filter is usually better than 2%.
8. Analyze three quality control blind spikes and three analyst spikes to ensure that instrument calibration is in control. Prepare spike as follows:
  - a. Using a microliter syringe, apply known volume of OC standard solution directly onto portion taken (step 5) from a precleaned blank filter.
  - b. Allow H<sub>2</sub>O to evaporate and analyze with samples and blanks (steps 10 and 11).
9. Determine instrument blank (results of analysis with no sample present) for each sample set.

**MEASUREMENT:**

10. Set analyzer according to manufacturer's recommendations (see APPENDIX B). Place sample portion into sample oven.  
NOTE: Forms of carbon that are difficult to oxidize (e.g., graphite) may require increased analysis time to ensure that all EC in the sample is quantified.

11. Determine EC (and OC) mass,  $\mu\text{g}$ , as provided by analyzer and divide by sample punch area,  $\text{cm}^2$ , to report result in terms of  $\mu\text{g C per cm}^2$  of filter.

#### CALCULATIONS:

12. Multiply the reported EC value by filter deposit area,  $\text{cm}^2$ , (typically  $8.55 \text{ cm}^2$  for a 37-mm filter) to calculate total mass,  $\mu\text{g}$ , of EC on each sample ( $W_{\text{EC}}$ ). Do the same for the blanks and calculate the mass found in the average field blank ( $W_{\text{b}}$ ). (OC masses may be calculated similarly.)
13. Calculate EC concentration ( $C_{\text{EC}}$ ) in the air volume sampled,  $V$  (L):

$$C_{\text{EC}} = \frac{W_{\text{EC}} - W_{\text{b}}}{V}, \text{ mg/m}^3$$

#### EVALUATION OF METHOD:

Currently, a suitable EC standard reference material is not available for verification of the accuracy of the method in the determination of EC. For this reason, only the accuracy of the method in the analysis of various OC standards and carbonaceous dusts for total carbon could be examined [1]. A commercial instrument was used for method evaluation [5]. No discernable differences in the responses of five different compounds were noted. Linear regression of the data for all five compounds gave a slope and correlation coefficient near unity [ $m = 0.99 (\pm 0.01)$ ,  $r^2 = 0.999$ ,  $n = 43$ ]. Based on results for individual compounds, reported carbon values are expected to be from 98 to 100% of the actual amount present. In addition, results (total carbon) of analysis of different carbonaceous materials were in good agreement with those reported by two other independent laboratories. These findings indicate that instrumental response appears to be compound- and matrix-independent (i.e., carbon is accurately quantified irrespective of compound and matrix type). Such a response is required for accurate carbon determination.

To calculate the estimated LOD of the method (i.e.,  $\approx 0.24 \mu\text{g C}$  or  $0.15 \mu\text{g C/cm}^2$ ), ethylenediaminetetraacetic acid (EDTA) calibration standards covering a range from  $0.23$  to  $2.82 \mu\text{g C}$  (or from  $0.15$  to  $1.83 \mu\text{g C per cm}^2$  of filter) were analyzed. Results of linear regression of the low-level calibration data (i.e.,  $\mu\text{g C}$  reported vs. actual) were then used to calculate the LOD as  $3 \sigma_y/m$  (where  $\sigma_y$  is the standard error of the regression and  $m$  is the slope of the regression line). The calculated LOD shows good agreement with that estimated as  $\text{LOD} = (\text{blank} + 3\sigma_{\text{blank}})$ , which gives a value of  $\approx 0.22 \mu\text{g C}$ . The mean ( $n = 40$ ) instrumental blank was  $\approx .02 (\pm 0.07) \mu\text{g C}$ .

Because the split between EC and OC is method-dependent [1,4], and no suitable EC standard exists for assessment of a particular method's accuracy, various methods can be compared on a relative basis only. At present, the thermal-optical method is considered unbiased (i.e., it is the reference method), and the overall precision reflects the method accuracy. The  $S_r$  of the mean EC concentration ( $4 \text{ mg/m}^3$ ) found using fourteen samplers (two each of seven types) for collection of diesel exhaust was 5.6%. Although pumps were used for sample collection, a 5% pump error was added in the calculation of the overall precision of the method because of the relatively small sample taken (0.5 h, 60 L). Based on the 95% confidence limit (19%; 13 degrees of freedom,  $n = 14$ ) on the accuracy, results of this experiment indicate that the NIOSH accuracy criterion [6] is fulfilled. The amount of EC collected ( $240 \mu\text{g per sample}$ ) would be equivalent to sampling an EC level of  $250 \mu\text{g/m}^3$  for 8 h at 2 L/min.

The thermal-optical method is applicable to nonvolatile, carbon-containing species only. The method is not appropriate for volatile or semivolatiles, which require sorbents for efficient collection. A complete discussion on the evaluation of this method for monitoring occupational exposures to particulate diesel exhaust in general industry can be found in the literature [1]. Application of the method for monitoring exposures to diesel particulate matter in the mining industry may require use of a size-selective sampling strategy in some situations [11]. In coal mines, a specialized impactor [2,3] with a sub- $\mu\text{m}$  cutpoint is required to minimize the contribution of coal-source EC [2].



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#### **METHOD WRITTEN BY:**

M. Eileen Birch, Ph.D., NIOSH/DPSE.

#### **APPENDIX A.**

Diesel exhaust has been classified by IARC as a probable human carcinogen [8]. NIOSH has recommended "...that whole diesel exhaust be regarded as a potential occupational carcinogen..." and that workers' exposures be reduced[9,10]. The American Conference of Governmental Hygienists (ACGIH) has proposed a TWA of 0.15 mg/m<sup>3</sup> for diesel particulate (see Notice of Intended Changes for 1995–1996) [12]. The TLV applies to submicrometer particulate matter, which includes the solid carbon particle core and particulate-adsorbed components. A submicrometer size fraction was selected so that interference of other larger dusts is minimized. If other submicrometer particulate (e.g., cigarette smoke, fumes, oil mists) is present, it will interfere in the gravimetric determination of diesel particulate.

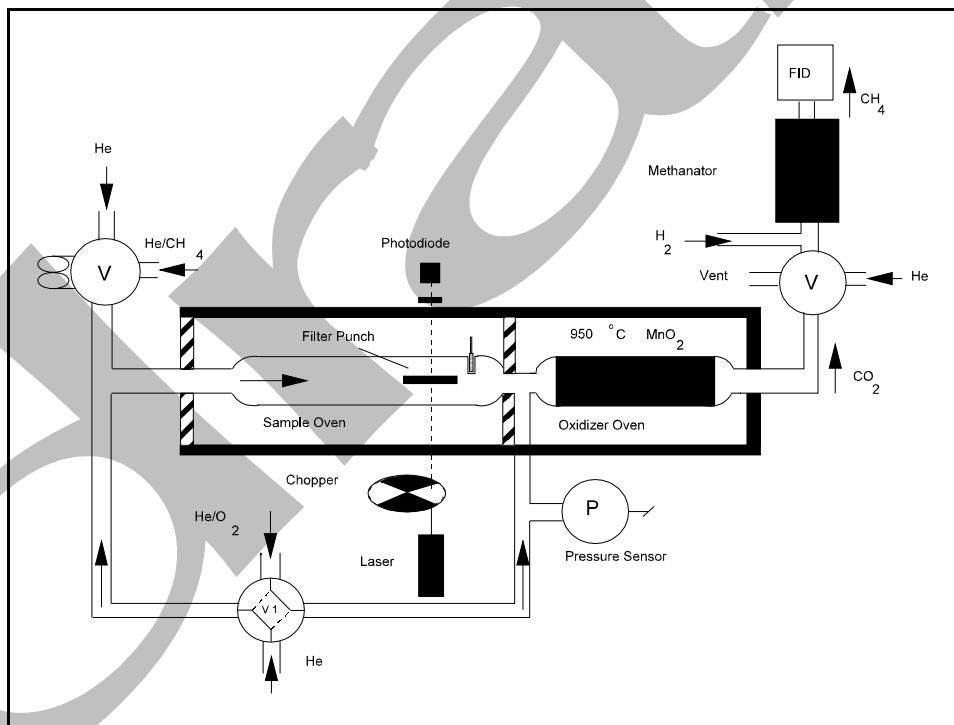
#### **APPENDIX B. THERMAL–OPTICAL ANALYZER DESIGN AND OPERATION:**

In the thermal-optical analysis of carbonaceous aerosols, speciation of various carbon types (organic, carbonate, and elemental) is accomplished through temperature and atmosphere control, and by continuous monitoring of filter transmittance. A schematic of the instrument is given below. The instrument is a modified version of a design previously described in the literature [11]. An optical feature corrects for pyrolytically generated elemental carbon (EC), or "char," which is formed during the analysis of some materials (e.g., cigarette smoke, pollen). He–Ne laser light passed through the filter allows continuous monitoring of filter

transmittance. Because temperatures in excess of 850°C are employed during the analysis, quartz-fiber filters are required for sample collection. A punch from the sample filter is taken for analysis, and organic carbon (OC) and elemental carbon are reported in terms of  $\mu\text{g}/\text{cm}^2$  of filter area. The total OC and EC on the filter are calculated by multiplying the reported values by the deposit area. In this approach, a homogeneous sample deposit is assumed. At the end of the analysis (after the EC is evolved), calibration is achieved through injection of a known volume of methane into the sample oven.

Thermal-optical analysis proceeds essentially in two stages. In the first, organic and carbonate carbon (if present) are evolved in an inert helium atmosphere as the temperature is raised (stepped) to about 850 °C. Evolved carbon is catalytically oxidized to  $\text{CO}_2$  in a bed of granular  $\text{MnO}_2$  (at 950°C),  $\text{CO}_2$  is reduced to  $\text{CH}_4$  in a Ni/firebrick methanator (at 450°C), and  $\text{CH}_4$  is quantified by an FID. In the second stage of the analysis, the oven temperature is reduced, an oxygen-helium mix (2%  $\text{O}_2$  in He) is introduced into the sample oven, and the oven temperature is again raised to about 850°C. As oxygen enters the oven, pyrolytically generated EC is oxidized and a concurrent increase in filter transmittance occurs. The point at which the filter transmittance reaches its initial value is defined as the "split" between EC and OC. Carbon evolved prior to the split is considered OC (or carbonate), and carbon volatilized after the split (excluding that from the  $\text{CH}_4$  standard) is considered elemental. The presence of carbonate can be verified through analysis of a second portion (punch) of the filter after its exposure to HCl vapor. In the second analysis, the absence of the suspect peak is indicative of carbonate carbon in the original sample.

Currently, only one commercial laboratory (Sunset Laboratory) performs thermal-optical analyses. To support the new method, a collaborative effort between NIOSH researchers and the instrument's developer is underway. During 1996, a thermal-optical instrument will be constructed and evaluated. This effort will assist in the transfer of this technology to other interested parties.



**Figure 1.** Schematic of Thermal-Optical Analyzer.

# APPENDIX C

## Side-By-Side Comparison of Methods for Measuring Both Total Particulate And The Benzene Soluble Fraction Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)

Asphalt Type and Sampling Date	Sampling Location	Concentration, milligrams per cubic meter			
		Regular Sampling Methods <sup>P</sup>		Combined Test Method <sup>†</sup>	
		Total Particulate	Benzene Solubles	Total Particulate	Benzene Solubles
<b>CRM Rubber Asphalt</b> 7/13/95	Paver Hopper	0.24	0.06	0.28	Trace
	Screed (Left)	1.0	0.56	1.2	0.89
	Screed (Right)	1.0	0.40	1.3	0.85
	Highway Background	0.09	ND	0.26	ND
<i>Minimum Detectable Concentration<sup>‡</sup></i>		<i>0.02</i>	<i>0.02</i>	<i>0.01</i>	<i>0.07</i>
<i>Minimum Quantifiable Concentration<sup>‡</sup></i>		<i>Not applicable</i>	<i>Not applicable</i>	<i>Not applicable</i>	<i>0.23</i>
<b>CRM Rubber Asphalt</b> 7/14/95	Paver Hopper	0.20	0.1	0.31	Trace
	Screed (Left)	1.2	0.98	1.3	1.5
	Screed (Right)	1.1	0.70	1.1	0.86
	Highway Background	0.15	ND	0.22	ND
<i>Minimum Detectable Concentration</i>		<i>0.02</i>	<i>0.03</i>	<i>0.01</i>	<i>0.09</i>
<i>Minimum Quantifiable Concentration</i>		<i>Not applicable</i>	<i>Not applicable</i>	<i>Not applicable</i>	<i>0.31</i>
<b>Conventional Asphalt</b> 8/22/95	Paver Hopper	0.22	ND	0.15	Trace
	Screed (Left)	0.25	Trace	ND	ND
	Screed (Right)	0.15	Trace	0.08	Trace
	Highway Background	ND	ND	ND	ND
<i>Minimum Detectable Concentration</i>		<i>0.03</i>	<i>0.08</i>	<i>0.01</i>	<i>0.08</i>
<i>Minimum Quantifiable Concentration</i>		<i>Not applicable</i>	<i>0.26</i>	<i>Not applicable</i>	<i>0.26</i>
<b>Conventional Asphalt</b> 8/23/95	Paver Hopper	0.18	Trace	0.21	Trace
	Screed (Left)	0.09	Trace	0.17	Trace
	Screed (Right)	0.13	ND	0.02	ND
	Highway Background	0.05	ND	ND	ND
<i>Minimum Detectable Concentration</i>		<i>0.02</i>	<i>0.08</i>	<i>0.01</i>	<i>0.08</i>
<i>Minimum Quantifiable Concentration</i>		<i>Not applicable</i>	<i>0.26</i>	<i>Not applicable</i>	<i>0.26</i>
<p><sup>P</sup> = NIOSH Sampling Method No. 0500 (total particulate collected on a tared polyvinyl chloride filter, followed by gravimetric analysis) and OSHA Analytical Method No. 58 (total particulate is collected on an unweighed Zefluor filter, then extracted with benzene and the benzene soluble fraction is gravimetrically analyzed) were the primary sampling and analytical techniques used in this evaluation.</p> <p><sup>†</sup> = The combined test method consists of a tared Zefluor filter which is gravimetrically analyzed (for total particulate), followed by analysis for benzene solubles by OSHA Analytical Method No. 58. The advantage to this method is that both total particulate and the benzene soluble fraction is obtained from a single filter sample.</p> <p>ND = Not detected (concentration is below the Minimum Detectable Concentration (MDC) for this sample set.</p> <p>Trace = Concentration is between the MDC and the Minimum Quantifiable Concentration (MQC) for this sample set.</p> <p><sup>‡</sup> = The MDC and MQC values will vary depending of the limits of detection and quantitation for a particular set of samples and the sample volume.</p>					

**Table 1**  
**Production and Equipment Information for I-64 Paving Project**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Description	8/22/95 Conventional Asphalt	8/23/95 Conventional Asphalt	7/13/95 CRM Asphalt	7/14/95 CRM Asphalt
<b>Pavement Function</b>	Two inch binder layer on the outer lane of I-64, westbound	Two inch binder layer on the outer lane of I-64, westbound	Open-graded base course on the outer lane of I-64, westbound	Open-graded base course on the outer lane of I-64, westbound
<b>Hot Mix Asphalt Type</b>	#9 Binder (INDOT mix design); Aggregate blend was 4% natural sand, 39% #9 stone, 34% #12 stone and 23% RAP	#9 Binder (INDOT mix design); Aggregate blend was 4% natural sand, 39% #9 stone, 34% #12 stone and 23% RAP	"5C" Base modified rubber hot mix asphalt; Aggregate blend was 92% #5 stone and 8% natural sand	"5C" Base modified rubber hot mix asphalt; Aggregate blend was 92% #5 stone and 8% natural sand
<b>Crude Supplier</b>	Marathon Oil, Louisville, KY	Marathon Oil, Louisville, KY	Marathon Oil, Louisville, KY	Marathon Oil, Louisville, KY
<b>AC Grade†</b>	AC-10	AC-10	AC-5	AC-5
<b>% Rubber (by weight)‡</b>	0%	0%	22% (Supplier: Baker Rubber, South Bend, IN)	22% (Supplier: Baker Rubber, South Bend, IN)
<b>Rubber Blending</b>	NA	NA	Wet Method	Wet Method
<b>Production, in metric tons</b>	2225 (2453 short tons)	1445 (1593 short tons)	1086 (1197 short tons)	1283 (1414 short tons)
<b>Laydown Temperature (range)</b>	121 to 129°C (250 to 265°F)	127 to 132°C (260 to 270°F)	116 to 132°C (240 to 270°F)	129 to 135°C (265 to 275°F)
<b>Mat Thickness</b>	5.1 cm	5.1 cm	7 cm	7 cm
<b>Laydown Width (Approximation)</b>	3.7 meters (12')	3.7 meters (12')	3.7 meters (12')	3.7 meters (12')
<b>Hot Mix Asphalt Conveyance</b>	Trucks dumped the HMA directly into paver hopper	Trucks dumped the HMA directly into paver hopper	Trucks dumped the HMA directly into paver hopper	Trucks dumped the HMA directly into paver hopper
<b>Emulsion Tack Coat</b>	Yes	Yes	Yes	Yes
<b>Job Duration (Approximation)</b>	7.5 hours	8 hours	10.5 hours	8 hours
<b>Transport</b>	Dump trucks (25 ton capacity per truck)	Dump trucks (25 ton capacity per truck)	Dump trucks (25 ton capacity per truck)	Dump trucks (25 ton capacity per truck)
<b>Windrower Pick-up</b>	No	No	No	No
<b>Paver</b>	Barber-Green (Model BG-240B)	Barber-Green (Model BG-240B)	Barber-Green (Model BG-240B)	Barber-Green (Model BG-240B)
<b>Roller (breakdown)</b>	Yes	Yes	Yes	Yes
<b>Roller (middle)</b>	Yes	Yes	Yes	Yes
<b>Roller (finishing)</b>	Yes	Yes	Yes	Yes
<b>Production Rate (Approximation)</b>	297 metric tons/hour	181 metric tons/hour	103 metric tons/hour	160 metric tons/hour

Conventional = Conventional Hot Mix Asphalt (HMA)

CRM = Crumb Rubber modified hot mix asphalt

mm = millimeters

RAP = Recycled asphalt pavement (a percentage of the old pavement is removed, ground up, and blended with the new hot mix asphalt).

According to the paving contractor, on August 22 and 23, 1995, approximately 23% RAP was being used.

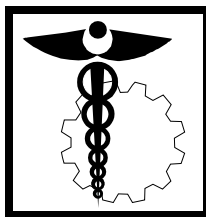
Wet Method = Rubber is blended with the asphalt cement prior to mixing it with aggregate.

‡Total weight of rubber by total weight of the asphalt/rubber blend

† = Asphalt cement

NA = Not Applicable

INDOT = Indiana Department of Transportation



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Through research and prevention**

**Table 2**  
**Summary of Sampling and Analytical Methods for I-64 Paving Project**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Substance	Flow Rate (Lpm)	Sample Media	Analytical Method	Comments
<b>Total Particulate</b>	2.0	Tared PVC filter (37 mm diameter, 0.8µm pore size)	NIOSH Method No. 0500, Gravimetric analysis	Both personal breathing-zone and area samples collected
<b>Respirable Particulate</b>	1.7	Tared PVC filter (37 mm diameter, 0.8µm pore size)	NIOSH Method No. 0600, Gravimetric analysis	Dorr-Oliver nylon cyclone used as particle size selector
<b>Polycyclic Aromatic Compounds (PACs) and Sulfur Compounds</b>	2.0	Zefluor filter (37 mm diameter, 2µm pore size), followed by an ORBO 42 sorbent tube	NIOSH 5506, modified to quantitate PACs via HPLC and a flow injection technique with spectrofluorometric detection. Two detector emission wavelengths were used: 370 nm (more sensitive to 2-3 ring PACs); and 400 nm (more sensitive to 4+ ring PACs). Sulfur compounds were analyzed by gas chromatography with sulfur chemiluminescence detection. This method may be found in Appendix A.	The collection method is similar to NIOSH method 5506, Polynuclear Aromatic Hydrocarbons. Opaque filter cassettes and sorbent tube holders were used to prevent the degradation of PACs by ultraviolet light. A detailed description of this method may be found in Appendix A.
<b>Benzene Soluble Particulate</b>	2.0	Zefluor filter (37 mm diameter)  ‡ <i>Note: In three NIOSH asphalt paving surveys conducted prior to this evaluation, a glass fiber filter was used.</i>	OSHA Method No. 58, with modifications†. The filters were rinsed with benzene, the leachate collected and evaporated, and the residue weighed to report the <i>benzene soluble fraction</i> . Organic compounds are generally soluble in benzene, whereas inorganic compounds are not benzene soluble. This method has been applied as an indirect measure of exposure to polynuclear aromatic hydrocarbons (PAHs) to evaluate a variety of exposure matrices including asphalt fume.	Because the method is nonspecific, the results are not necessarily due to PAH compounds. This method was used since it has been reported in many asphalt investigations and will also allow comparison of the conventional and CRM asphalt paving operations.
<b>Elemental/Organic Carbon</b>	2.0	Quartz-fiber filters (37 mm diameter, open face)	A rectangular punch (1.54 cm <sup>2</sup> ) is taken from the quartz filter for a three stage thermal-optical analysis.	A draft copy of NIOSH Method 5040 is provided as Appendix B.
<b>Metals</b>	2.5	Mixed cellulose ester (MCE) membrane filters (37 mm diameter)	NIOSH Method No. 7300. The samples were wet-ashed with concentrated nitric and perchloric acids. The residues were dissolved in a dilute solution of the same acids and the resulting solutions were analyzed for metals and minerals via Inductively Coupled Argon Plasma, Atomic Emission Spectroscopy (ICP-AES).	Analyses included silver, aluminum, arsenic, barium, beryllium, calcium, cadmium, cobalt, chromium, copper, iron, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorous, lead, platinum, selenium, tellurium, thallium, titanium, vanadium, yttrium, zinc, and zirconium.
<b>Qualitative Volatile Organic Compound (VOC) Screen</b>	0.02	Thermal desorption tubes	Samples analyzed using the Tekmar thermal desorber interfaced directly to a gas chromatograph and a mass spectrometry detector (GC/MS).	Each thermal desorption (TD) tube contains three beds of sorbent materials: (1) a front layer of Carbotrap C; (2) a middle layer of Carbotrap; and (3) a back section of Carbosieve S-III.

**Table 2  
Summary of Sampling and Analytical Methods for I-64 Paving Project  
Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Substance	Flow Rate (Lpm)	Sample Media	Analytical Method	Comments												
<b>Quantitative Analysis for Selected Solvents</b>	0.2	Activated charcoal sorbent tubes (100 milligram front section/50 milligram back section)	Currently existing NIOSH methods were merged and modified (i.e. NIOSH Methods 1300 and 1301 for ketones, 1501 for aromatic hydrocarbons, and 1550 for petroleum distillates.) The activated charcoal was desorbed with carbon disulfide; an aliquot of this solution was analyzed using GC-FID.	Specific VOCs that were quantified included benzene, toluene, MIBK, and petroleum distillates (other hydrocarbons with retention times greater than toluene).												
<b>H<sub>2</sub>S, SO<sub>2</sub>, CO, and Ozone</b>	Diffusion	Toxilog® diffusion monitors for H <sub>2</sub> S, SO <sub>2</sub> , CO. CEA® TG-KA Portable Toxic Gas Detector for ozone	Toxilog® diffusion monitors use individual electrochemical sensors specific for H <sub>2</sub> S, SO <sub>2</sub> , CO. The CEA® TG-KA Portable Toxic Gas Detector for ozone uses an electrochemical galvanic cell method.	Spot measurements were made throughout the work day around the paving site.												
<b>Mutagenic Potential</b>	≈ 10	Zefluor filter (37 mm diameter)	Mutagenic activity evaluated via a modified Ames testing protocol. The basic analytical procedure used has been described by Maron and Ames except it was to be conducted using a spiral plater device as described by Houk et al. ( <u>Environ. Mol. Mut.</u> , 1991, <u>17</u> , 112-121; and <u>Mut. Res.</u> 1989, <u>223</u> , 49-64).	Area samples were collected in the plume over an open port of a heated asphalt cement storage tank at the hot mix plant. The results of this modified Ames testing will be discussed in a separate NIOSH report.												
<b>Test Method: Total Particulate and Benzene Soluble Particulate</b>	2.0	Tared Zefluor filter (37 mm diameter)	The samples were gravimetrically analyzed for total particulate, followed by an analysis for benzene solubles using the OSHA 58 method (see previous page) with the following modifications: (1) the samples were not transferred to scintillation vials before shipment; (2) Gelman Acrodisc® CR were used instead of 13 mm stainless steel filters; and (3) the air samples were collected on Zefluor polytetrafluoroethane filters rather than the recommended glass fiber filters. This combined total particulate + benzene soluble fraction method was used for both personal breathing-zone and area air samples on subsequent NIOSH asphalt paving surveys.	This test method combines two previously separate sampling and analytical methods (total particulate using gravimetric analysis and benzene solubles using OSHA Method No. 58 (with modifications)). This method has not been assigned a NIOSH Sampling and Analytical Method Number.												
<p><b>The following are abbreviations which were not spelled out in the table.</b></p> <table border="0"> <tr> <td>PVC = Polyvinyl chloride sampling filter</td> <td>SO<sub>2</sub> = Sulfur dioxide</td> </tr> <tr> <td>mm = millimeter</td> <td>CO = Carbon monoxide</td> </tr> <tr> <td>µm = micrometer</td> <td>lpm = Liters per minute</td> </tr> <tr> <td>GC-FID = Gas chromatography-flame ionization detector</td> <td>MIBK = Methyl isobutyl ketone</td> </tr> <tr> <td>H<sub>2</sub>S = Hydrogen sulfide</td> <td>Zefluor = Teflon® sampling filter</td> </tr> <tr> <td>HPLC = High pressure liquid chromatography</td> <td>nm = Nanometer</td> </tr> </table>					PVC = Polyvinyl chloride sampling filter	SO <sub>2</sub> = Sulfur dioxide	mm = millimeter	CO = Carbon monoxide	µm = micrometer	lpm = Liters per minute	GC-FID = Gas chromatography-flame ionization detector	MIBK = Methyl isobutyl ketone	H <sub>2</sub> S = Hydrogen sulfide	Zefluor = Teflon® sampling filter	HPLC = High pressure liquid chromatography	nm = Nanometer
PVC = Polyvinyl chloride sampling filter	SO <sub>2</sub> = Sulfur dioxide															
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HPLC = High pressure liquid chromatography	nm = Nanometer															

**Table 3**  
**Toxicity and Exposure Criteria Information for I-64 Paving Project**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Compound	Toxicity Review	Exposure Criteria
<b>Asphalt Fume</b>  <b>(As Total Particulate)</b>	<p>Although the composition of asphalt fume cannot be easily characterized, one evaluation technique has been to sample total particulate. Total particulate is a measure of all airborne particulate which was collected on the sample filter. Current occupational exposure criteria from NIOSH and ACGIH for asphalt fume are expressed as total particulate. Asphalt fume has also been measured as the benzene soluble particulate fraction (BSF), a surrogate of exposure to polynuclear aromatic hydrocarbons (PAHs, see discussion below). Asphalt consists primarily of polycyclic aromatic compounds (PACs), many of which are soluble in benzene. These substances are of concern due to their irritancy and cancer-causing potential.</p>	<p>The NIOSH REL is 5 mg/m<sup>3</sup> for a 15-minute ceiling exposure.</p> <p>There is no current OSHA PEL for asphalt fume.</p> <p>The ACGIH TLV® is 5 mg/m<sup>3</sup> as an 8-hour TWA to total particulate.</p>
<b>Respirable Particulate</b>	<p>In contrast to total particulate, a respirable particulate sample uses a selection device to obtain the fraction of the airborne particulate that is small enough to be retained in the respiratory system once inhaled.</p> <p>Any conclusions based on respirable (or total) particulate concentrations may be misleading since other potentially toxic substances may be present. These particulate concentrations, along with the results obtained from tests for individual components (such as polycyclic aromatic compounds [PACs], benzene solubles, and selected solvents) should be considered together when determining the degree of hazard.</p>	<p>No NIOSH REL</p> <p>The OSHA PEL is 5 mg/m<sup>3</sup>, 8-hour TWA.</p> <p>The ACGIH TLV® for particulates not otherwise classified is 10 mg/m<sup>3</sup> for inhalable particulate and 3 mg/m<sup>3</sup> for respirable particulate. Both are 8-hour TWAs.</p>
<b>Benzene Soluble Particulate</b>	<p>The benzene soluble particulate fraction (BSF) is that portion of the total particulate that is soluble in benzene. Organic compounds are generally soluble in benzene, whereas inorganic compounds are not benzene soluble.</p> <p>Historically, the BSF concentrations were measured in asphalt studies in an attempt to differentiate exposure between the asphalt fume and dirt or other dust present at asphalt construction operations. However, this method is non-specific and the BSF results are not necessarily due to polycyclic aromatic compounds (PACs) or polynuclear aromatic hydrocarbons (PAHs).</p>	<p>None established for BSF associated with asphalt fume</p>
<b>Polynuclear Aromatic Hydrocarbons</b>  <b>and</b>  <b>Polycyclic Aromatic Compounds</b>	<p>Analysis for unsubstituted PAHs has been applied to evaluate asphalt fume exposure. However, this approach provides limited information because asphalt fume contains numerous alkylated PACs that coelute, causing chromatographic interference, which prevents quantitation of specific compounds.</p> <p>Polycyclic aromatic compounds refers to a set of cyclic organic compounds that includes PAHs and also includes compounds that may have sulfur, nitrogen, or oxygen in the ring structure and alkyl substituted cyclics. Hundreds of PACs with varying degrees of alkyl substitutions are typically associated with asphalt materials [Lunsford et al. 1989]. PAHs have received considerable attention since some have been shown to be carcinogenic in experimental animals.</p> <p>NIOSH investigators have hypothesized that PACs with 2 to 3 rings (referred to in this report as PAC<sub>370</sub>) are associated with more irritative effects, while the 4 to 7 ring PACs (termed PAC<sub>400</sub>) may have more carcinogenic and/or mutagenic effects. It is not currently possible to definitively distinguish between these two PAC groups analytically; however, using two different spectrofluorometric detector wavelengths (370 nanometer [nm] and 400 nm) allows the detector to be more sensitive to PACs based on ring number. A more complete discussion of the NIOSH analytical method for PACs may be found in Appendix A.</p>	<p>None established for PAHs and PACs as a class.</p>

**Table 3**  
**Toxicity and Exposure Criteria Information for I-64 Paving Project**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Compound	Toxicity Review	Exposure Criteria
<b>Benzothiazole</b>	In its pure form, benzothiazole is a yellow liquid with an unpleasant odor [Sax 1987]. It is used as a rubber vulcanization accelerator [ILO 1971], as an antimicrobial agent [Ito 1978], and in dyes [Kirk 1978]. Benzothiazole was identified in the air during rubber vulcanization [Rappaport 1977]. Reports also indicate that benzothiazole is present in tires and CRM asphalt. Benzothiazole was selected for study since it may be useful as an indicator to represent the complex exposures resulting from CRM asphalt paving. It is not known if there are any health effects associated with benzothiazole at the air concentrations measured in this study.	None established
<b>Other Sulfur-Containing Compounds</b>	The addition of tire rubber may increase sulfur compounds in asphalt. In this report "other sulfur-containing compounds" refer to aliphatic and aromatic organic compounds that contain sulfur. Although no specific occupational exposure limits exist for this group of sulfur compounds, it was hypothesized that some of these compounds may cause respiratory irritation.	None established
<b>Organic and Elemental Carbon</b>	Measuring organic, elemental, and total carbon concentrations (and determining a ratio between elemental and total carbon) provides an indication of diesel exhaust exposure. Any elemental carbon above background will most likely be from diesel exhaust. Unfortunately, this method cannot be used to specifically differentiate carbon sources (i.e., asphalt fume, diesel exhaust, cigarette smoke).  There are no occupational exposure criteria for either elemental or organic carbon. This method was employed previously in several NIOSH trucking industry studies [Zaebst et al 1991, Blade et al. 1989]. A copy of the draft NIOSH Method 5040 is provided in Appendix B.	None established
<b>MIBK</b>	Tire rubber may be a source for methyl isobutyl ketone (MIBK) since this organic compound can be used as an antioxidant in the tire manufacturing process. In its pure form, MIBK is a colorless, flammable organic solvent that is typically used as a solvent in the surface coating and synthetic resin industries [ACGIH 1992]. This solvent is absorbed primarily through inhalation and causes irritation of the eyes, mucous membranes, and skin [Hathaway 1991]. At air concentrations much higher than were measured in this asphalt study, MIBK has caused central nervous system depression [Hathaway 1991]. Continued or prolonged skin contact with the liquid can cause dermatitis [Hathaway 1991].	The NIOSH REL and ACGIH TLV are 50 ppm, 8-hour TWA; and 75 ppm, 15 minute STEL.  OSHA PEL is 100 ppm for an 8-hour TWA.
<b>Benzene</b>	Acute benzene overexposure can cause central nervous system depression with symptoms such as headache, nausea, and drowsiness. Chronic exposure to benzene has been associated with the depression of the hematopoietic system and is associated with an increased incidence of leukemia and possibly multiple myeloma [ACGIH 1992]. NIOSH classifies benzene as a human carcinogen [NIOSH 1992]. *Note: ACGIH has proposed to lower its TLV® for benzene to 0.3 ppm with a skin notation (indicating that skin exposure contributes to the overall absorbed inhalation dose and potential effects), and classify it as a proven human carcinogen [ACGIH 1996].	NIOSH REL is to reduce exposures to the lowest feasible level.  OSHA PEL is 1 ppm for an 8-hour TWA.  ACGIH TLV is 10 ppm* for an 8-hour TWA.
<b>Toluene</b>	Toluene can cause acute irritation of the eyes, respiratory tract, and skin. Since it is a defatting solvent, repeated or prolonged skin contact will remove the natural lipids from the skin which can cause drying, fissuring, and dermatitis [Proctor 1989, NIOSH 1973]. Studies have shown that subjects exposed to 100 ppm of toluene for six hours complained of eye and nose irritation, and in some cases, headache, dizziness, and a feeling of intoxication (narcosis) [WHO 1981]. No symptoms were noted below 100 ppm in other studies [Bruckner 1981a,b]. The ACGIH TLV® carries a skin notation, indicating that skin exposure contributes to the overall absorbed inhalation dose and potential effects [ACGIH 1996].	NIOSH REL is 100 ppm, 8-hour TWA (15-minute STEL of 150 ppm).  OSHA PEL is 200 ppm, 8-hour TWA; 300 ppm for a ceiling limit (not to be exceeded at any time).  ACGIH TLV is 50 ppm, 8-hour TWA (skin).



**Table 3  
Toxicity and Exposure Criteria Information for I-64 Paving Project  
Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Compound	Toxicity Review	Exposure Criteria
<b>Xylene</b>	Structurally similar to toluene, xylene can also cause acute irritation of the eyes, respiratory tract, and skin [Hathaway 1991]. In previous studies, humans exposed to concentrations ranging from 60 to 350 ppm (concentrations much higher than were measured in this asphalt study) experienced giddiness, anorexia (loss of appetite), and vomiting [Hathaway 1991].	<p>NIOSH REL is 100 ppm, 8-hour TWA.</p> <p>OSHA PEL is 100 ppm, 8-hour TWA.</p> <p>ACGIH TLV is 100 ppm for an 8-hour TWA and 150 ppm for a 15-minute STEL</p>
<b>Total Hydrocarbons</b>  <b>(as either n-hexane or Stoddard solvent)</b>	In this study, total hydrocarbons (HC) were quantified as either n-hexane or as Stoddard solvent, a petroleum distillate mixture. Effects from exposure to either n-hexane or Stoddard solvent are primarily acute (such as upper respiratory irritation, nausea, headaches, and irritation of the eyes and nose), unless significant amounts of substances that have chronic toxicity are present, such as benzene or glycol ethers[Proctor 1991]. Epidemiologic studies have shown that exposure to similarly refined petroleum solvents (i.e.,Stoddard solvent, mineral spirits) can cause dry throat, burning or tearing of the eyes, mild headaches, dizziness, central nervous system depression, respiratory irritation, and dermatitis [NIOSH 1977b]. The evaluation criteria are based upon the similarity of the mixture composition in relation to the most commonly available products (in this case either n-hexane or Stoddard solvent).	<p>NIOSH REL is 350 mg/m<sup>3</sup>, 10-hour TWA (for all petroleum distillate mixtures, including Stoddard solvent). The NIOSH ceiling limit is 1800 mg/m<sup>3</sup>, 15 minutes.</p> <p>OSHA PEL for Stoddard solvent is 2,900 mg/m<sup>3</sup>, 8-hour TWA.</p> <p>ACGIH TLV for Stoddard solvent is 525 mg/m<sup>3</sup>, 8-hour TWA.</p> <hr/> <p>NIOSH REL for n-hexane is 180 mg/m<sup>3</sup> for up to a 10-hour TWA.</p> <p>OSHA PEL for n-hexane is 1,800 mg/m<sup>3</sup>, 8-hour TWA.</p> <p>ACGIH TLV for n-hexane is 176 mg/m<sup>3</sup>, 8-hour TWA.</p>

**Abbreviations:**

REL = Recommended Exposure Limit (NIOSH)  
 TLV = Threshold Limit Value (ACGIH)  
 STEL = Short-term exposure limit  
 μm = micrometers

PEL = Permissible Exposure Limit (OSHA)  
 TWA = Time-weighted average  
 ppm = parts per million  
 mg/m<sup>3</sup> = milligrams per cubic meter

**Table 4**  
**Summary of Environmental Conditions for I-64 Paving Project**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Description	8/22/95 Conventional Asphalt	8/23/95 Conventional Asphalt	7/13/95 CRM Asphalt	7/14/95 CRM Asphalt
Summary	Sunny, hot, and dry	Sunny, hot, and dry	Sunny, hot, and dry	Sunny, hot, and dry
Minimum Temperature	29°C‡ (85°F)‡	17°C (63°F)	29°C (85°F)†	32°C (89°F)†
Maximum Temperature	33°C (91°F)	32°C (89°F)	38°C (100°F)	41°C (105°F)
Humidity (Range)	44 to 49%	38 to 58%	44 to 61%	41 to 65%
Humidity (Average)	46%	47%	51%	50%
Minimum WBGT <sub>OUT</sub>	78.3°F	64.0°F	84.2°F	84.2°F
Maximum WBGT <sub>OUT</sub>	81.1°F	81.5°F	91.4°F	93.7°F
Wind Speed	Steady breeze 5 to 10 mph	Steady breeze 3 to 7 mph	Steady breeze 3 to 5 mph (Wind gusts to 7 mph)	Steady breeze 2 to 5 mph (Wind gusts to 7 mph)
Wind Direction	50° to 90° (Winds from the northeast and east)	60° to 110° (Winds from the northeast and southeast)	230 to 260° (Winds from southwest)	250 to 290° (Winds from the west)
Estimated Traffic Density	Low	Low	Low	Low

‡ = Did not collect the first temperature and humidity reading on 8/22/95 until late morning. This accounts for the higher minimum temperature reported in this table. The weather conditions on both 8/22 and 8/23/95 were very similar.

† = Did not collect the first temperature and humidity readings on 7/13/95 and 7/14/95 until mid-morning, accounting for the higher minimum temperatures reported in this table. It is estimated that the minimum temperatures on these days (at the beginning of the paving period) was in the mid to upper 70's.

WBGT = Wet bulb globe temperature, a heat stress index

Conventional = Hot mix asphalt which does not contain crumb rubber

CRM = Crumb rubber modified hot mix asphalt

Note: Wind direction is expressed in degrees, ranging from 0° to 360°. Zero degrees (0°) refers to wind from the north; 90° describes wind from the east; 180° refers to wind from the south; and 270° is wind from the west.

**Table 5**  
**Total Particulate Concentrations: Area Samples**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Sampling Date	Area	Sampling Time	Volume (Liters)	Concentration, mg/m <sup>3</sup>
<b>Conventional Asphalt</b> <b>8/22/95</b>	Paver Hopper	8:27 am → 3:44 pm	874	0.22
	Screed (Left)	8:44 am → 3:48 pm	848	0.25
	Screed (Right)	8:19 am → 3:50 pm	902	0.15
	Highway Background (1)	9:22 am → 4:10 pm	816	ND (<0.02)
	Highway Background (2)	10:30 am → 4:04 pm	668	ND (<0.02)
	Highway Background (3)	10:34 am → 4:00 pm	652	0.10
<b>Conventional Asphalt</b> <b>8/23/95</b>	Paver Hopper	7:54 am → 3:16 pm	884	0.18
	Screed (Left)	7:46 am → 3:16 pm	900	0.09
	Screed (Right)	7:38 am → 3:16 pm	916	0.13
	Highway Background (1)	7:10 am → 3:31 pm	1002	0.05
	Highway Background (2)	7:30 am → 3:25 pm	950	ND (<0.02)
	Highway Background (3)	7:34 am → 3:23 pm	938	0.05
<b>CRM Asphalt</b> <b>7/13/95</b>	Paver Hopper	7:13 am → 5:25 pm	1224	0.24
	Screed (Left)	7:15 am → 5:28 pm	1070	1.0
	Screed (Right)	7:17 am → 5:27 pm†	860	1.0
	Highway Background (1)	7:02 am → 5:40 pm	1276	0.09
	Highway Background (2)	7:41 am → 5:39 pm	1200	0.13
	Highway Background (3)	7:50 am → 5:38 pm	1176	0.16
<b>CRM Asphalt</b> <b>7/14/95</b>	Paver Hopper	7:49 am → 3:42 pm‡	732	0.20
	Screed (Left)	7:38 am → 3:40 pm‡	746	1.2
	Screed (Right)	7:38 am → 3:40 pm‡	746	1.1
	Highway Background (1)	7:48 am → 4:02 pm	988	0.15
	Highway Background (2)	8:05 am → 3:59 pm	946	0.08
	Highway Background (3)	8:07 am → 3:56 pm	944	0.03
† = Tubing came loose from pump. Reconnected at 10:00 am. ‡ = Pumps truned off between 12:18 pm to 2:07 pm since no paving was being performed. ND = Not Detected (below the Minimum Detectable Concentration) ( ) = The value which is shown in brackets is the minimum detectable concentration (MDC) for this sample. The MDC is calculated by dividing the analytical Limit of Detection by the air sample volume and is reported as a less than (<) value.				

**Table 6**  
**Respirable Particulate Concentrations: Area Samples**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Sampling Date	Area	Sampling Time	Sample Volume (Liters)	Concentration, mg/m <sup>3</sup>
<b>Conventional Asphalt</b> <b>8/22/95</b>	Paver Hopper	8:27 am → 3:44 pm	743	0.03
	Screed (Left)	8:44 am → 3:48 pm	721	0.17
	Screed (Right)	8:19 am → 3:50 pm	767	0.04
	Highway Background	9:22 am → 4:10 pm	694	ND (<0.03)
<b>Conventional Asphalt</b> <b>8/23/95</b>	Paver Hopper	7:54 am → 3:16 pm	751	0.11
	Screed (Left)	7:46 am → 3:16 pm	765	0.09
	Screed (Right)	7:38 am → 3:16 pm	779	0.04
	Highway Background	7:10 am → 3:31 pm	852	ND (<0.03)
<b>CRM Asphalt</b> <b>7/13/95</b>	Paver Hopper	7:13 am → 5:25 pm†	860	0.16
	Screed (Left)	7:15 am → 5:28 pm	910	0.58
	Screed (Right)	7:17 am → 5:27 pm	901	0.51
	Highway Background	7:02 am → 5:40 pm	1085	0.14
<b>CRM Asphalt</b> <b>7/14/95</b>	Paver Hopper	7:49 am → 3:42 pm‡	622	0.18
	Screed (Left)	7:38 am → 3:40 pm‡	634	0.33
	Screed (Right)	7:38 am → 3:40 pm‡	634	0.38
	Highway Background	7:48 am → 4:02 pm	840	ND (<0.03)

† Pump faulted after 41 minutes. Pump restarted at 9:40 am.

‡ Pumps turned off between 12:18 pm to 2:07 pm since no paving was being performed.

ND = Not Detected (below the Minimum Detectable Concentration)

( ) = The value which is shown in brackets is the minimum detectable concentration (MDC) for this sample. The MDC is calculated by dividing the analytical Limit of Detection by the air sample volume and is reported as a less than (<) value.

**Table 7**  
**Benzene Soluble Particulate Concentrations: Area Samples**  
**Paving Company: Koester Equipment, Evansville, IN (HETA 95-0307)**

Sampling Date	Area	Sampling Time	Sample Volume (Liters)	Concentration, mg/m <sup>3</sup>	
<b>Conventional Asphalt</b> <b>8/22/95</b>	Paver Hopper	8:27 am → 3:44 pm	874	ND	
	Screed (Left)	8:44 am → 3:48 pm	848	Trace	
	Screed (Right)	8:19 am → 3:50 pm	902	Trace	
	Highway Background	9:22 am → 4:10 pm	696	ND	
	<i>Minimum Detectable Concentration (900 Liter air sample)</i>				<i>0.08</i>
	<i>Minimum Quantifiable Concentration (900 Liter air sample)</i>				<i>0.26</i>
<b>Conventional Asphalt</b> <b>8/23/95</b>	Paver Hopper	7:54 am → 3:16 pm	884	Trace	
	Screed (Left)	7:46 am → 3:16 pm	900	Trace	
	Screed (Right)	7:38 am → 3:16 pm	916	ND	
	Highway Background	7:10 am → 3:31 pm	1002	ND	
	<i>Minimum Detectable Concentration (900 Liter air sample)</i>				<i>0.08</i>
	<i>Minimum Quantifiable Concentration (900 Liter air sample)</i>				<i>0.26</i>
<b>CRM Asphalt</b> <b>7/13/95</b>	Paver Hopper	7:13 am → 5:25 pm	1224	0.06	
	Screed (Left)	7:15 am → 5:28 pm	1070	0.56	
	Screed (Right)	7:17 am → 5:27 pm	1060	0.40	
	Highway Background	7:02 am → 5:40 pm	1276	ND	
	<i>Minimum Detectable Concentration (1200 Liter air sample)</i>				<i>0.02</i>
	<i>Minimum Quantifiable Concentration (1200 Liter air sample)</i>				<i>0.06</i>
<b>CRM Asphalt</b> <b>7/14/95</b>	Paver Hopper	7:49 am → 3:42 pm	732	0.10	
	Screed (Left)	7:38 am → 3:40 pm	746	0.98	
	Screed (Right)	7:38 am → 3:40 pm	746	0.70	
	Highway Background	7:48 am → 4:02 pm	988	ND	
	<i>Minimum Detectable Concentration (800 Liter air sample)</i>				<i>0.03</i>
	<i>Minimum Quantifiable Concentration (800 Liter air sample)</i>				<i>0.09</i>
<p>ND = Not Detected (below the Minimum Detectable Concentration, MDC). The MDC is calculated by dividing the analytical Limit of Detection by the air sample volume.</p> <p>Trace = The concentration is between the MDC and the Minimum Quantifiable Concentration (MQC). Please note that the MDC and the MQC will vary depending on the LOD and LOQ of the sample set and the sample volume.</p>					

**Table 8**  
**Polycyclic Aromatic Compounds (PACs) Concentrations: Area Samples**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Sampling Date	Area	Sampling Time (minutes)	Sample Volume (Liters)	Air Concentration, micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ )			
				PACs <sub>370</sub>	PACs <sub>400</sub>	SulCom	Benzothiazole
<b>Conventional Asphalt</b> 8/22/95	Paver Hopper	437‡	874	45	5.1	ND (<1.3)	ND (<1.3)
	Screed (Left)	424	848	22	2.9	70	ND (<1.3)
	Screed (Right)	451	902	14	1.9	70	Trace
	Highway Background	408	816	ND	ND	11	Trace
<b>Conventional Asphalt</b> 8/23/95	Paver Hopper	442	884	35	4.8	97	ND (<1.2)
	Screed (Left)	440	880	49	6.0	105	ND (<1.2)
	Screed (Right)	448	896	19	2.4	47	ND (<1.2)
	Highway Background	501	1002	Trace	ND	ND (<1.1)	ND (<1.1)
<b>CRM Asphalt</b> 7/13/95	Paver Hopper	612	1224	143	6.4	51	31
	Screed (Left)	535	1070	143	22	255	61
	Screed (Right)	500	1000	153	26	296	67
	Highway Background	638	1276	0.2	Trace	ND (<1.2)	ND (<1.2)
<b>CRM Asphalt</b> 7/14/95	Paver Hopper	366	732	41	6.1	84	89
	Screed (Left)	373	746	216	35	792	127
	Screed (Right)	312	624	84	16	164	125
	Highway Background	494	988	0.4	0.04	ND (<1.5)	ND (<1.5)

‡ = Sampling pump failed twice during the work day. Concentration based on estimated sample volume.  
SulCom = Other sulfur-containing compounds  
370 nm = 370 nanometers, including both vapor and particulate phase  
400 nm = 400 nanometers, including both vapor and particulate phase  
Trace = Concentration is between the Minimum Detectable and Minimum Quantifiable Concentrations  
ND = Not Detected (below the Minimum Detectable Concentration)  
( ) = The value which is shown in brackets is the minimum detectable concentration (MDC) for this sample. The MDC is calculated by dividing the analytical Limit of Detection by the air sample volume and is reported as a less than (<) value.

Comments:

1. Air samples were collected using 37 millimeter Zefluor® filters followed by an ORBO 43 sorbent tube.
2. The PACs concentrations reported in this table include both the particulate phase (collected on the filter) and the vapor phase (from the sorbent tube).

**Table 9**  
**Elemental Carbon Concentrations: Area Samples**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Sampling Date	Area	Sampling Time	Sample Volume (Liters)	Concentration, $\mu\text{g}/\text{m}^3$			EC:TC
				Organic Carbon (OC)	Elemental Carbon (EC)	Total Carbon (TC)	
<b>Conventional Asphalt</b> 8/22/95	Paver Hopper	8:27 am → 3:44 pm	874	Samples lost during analysis			
	Screed (Left)	8:44 am → 3:48 pm	848	Samples lost during analysis			
	Screed (Right)	8:19 am → 3:50 pm	902	Samples lost during analysis			
	Highway Background	9:22 am → 4:10 pm	816	Samples lost during analysis			
<b>Conventional Asphalt</b> 8/23/95	Paver Hopper	7:54 am → 3:16 pm	884	Samples lost during analysis			
	Screed (Left)	7:46 am → 3:16 pm	900	Samples lost during analysis			
	Screed (Right)	7:38 am → 3:16 pm	916	Samples lost during analysis			
	Highway Background	7:10 am → 3:31 pm	1002	Samples lost during analysis			
<b>CRM Asphalt</b> 7/13/95	Paver Hopper	7:13 am → 5:25 pm	1224	133	8.7	142	6%
	Screed (Left)	7:15 am → 5:28 pm	1070	716	11	727	1.4%
	Screed (Right)	7:17 am → 5:27 pm	1060	765	13	777	1.6%
	Highway Background	8:07 am → 5:40 pm	1276	29	1.6	31	5.2%
<b>CRM Asphalt</b> 7/14/95	Paver Hopper	7:49 am → 3:42 pm	732	244	9.0	253	3.6%
	Screed (Left)	7:38 am → 3:40 pm	746	880	12	892	1.4%
	Screed (Right)	7:38 am → 3:40 pm	746	846	14	860	1.6%
	Highway Background	7:48 am → 4:02 pm	988	31	3.7	34	11%

$\mu\text{g}/\text{m}^3$  = Micrograms per cubic meter  
 EC:TC = Ratio of Elemental Carbon to Total Carbon

The air samples collected for elemental and organic carbon on August 22-23, 1995, were lost during analysis and no results can be reported. Since the same paving equipment was being throughout this survey, it is assumed that the EC:TC ratios would have remained the same regardless of whether conventional or CRM asphalt was being applied.

**Table 10**  
**Selected Volatile Organic Compounds (VOCs) Concentrations: Area Samples**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Sampling Date	Area	Sampling Time (minutes)	Sample Volume (Liters)	Concentration, expressed in parts per million				Concentration, expressed in mg/m <sup>3</sup>	
				Benzene	Toluene	Xylene	MIBK	Total HC< Toluene†	Total HC> Toluene‡
<b>Conventional Asphalt Paving</b> 8/22/95	Paver Hopper	437	87	ND	ND	ND	ND	Trace	4.9
	Screed (Right)	451	90	ND	ND	ND	ND	ND	1.2
	Screed (Left)	424	85	ND	ND	ND	ND	Trace	2.9
	Highway Background	408	82	ND	ND	ND	ND	ND	ND
<b>Conventional Asphalt Paving</b> 8/23/95	Paver Hopper	422	88	ND	ND	ND	ND	0.16	63.
	Screed (Right)	458	92	ND	ND	ND	ND	Trace	2.3
	Screed (Left)	440	88	ND	ND	ND	ND	0.17	5.0
	Highway Background	501	100	ND	ND	ND	ND	ND	ND
<b>CRM Asphalt Paving</b> 7/13/95	Paver Hopper	612	122	ND	ND	Trace	Trace	ND	2.5
	Screed (Right)	530	106	Trace	ND	Trace	0.12	0.17	8.5
	Screed (Left)	535	107	Trace	ND	Trace	0.92	0.21	10
	Highway Background	638	128	ND	ND	ND	ND	ND	ND
<b>CRM Asphalt Paving</b> 7/14/95	Paver Hopper	366	73	ND	ND	ND	ND	ND	1.9
	Screed (Right)	373	75	ND	ND	0.042	0.13	0.25	19
	Screed (Left)	373	75	ND	ND	ND	ND	ND	Trace
	Highway Background	494	99	ND	ND	ND	ND	ND	ND
Minimum Detectable Concentration (assuming a 100 Liter air sample)				0.0062	0.010	0.0091	0.024	0.02	0.04
Minimum Quantifiable Concentration (assuming a 100 Liter air sample)				0.018	0.034	0.032	0.079	0.06	0.13
† = Total hydrocarbons with a gas chromatograph retention time less than (<) toluene. These concentrations are expressed as n-hexane in milligrams per cubic meter (mg/m <sup>3</sup> ). ‡ = Total hydrocarbons with a gas chromatograph retention time greater than (>) toluene. These concentrations are expressed as Stoddard Solvent in milligrams per cubic meter (mg/m <sup>3</sup> ). MIBK = Methyl isobutyl ketone Trace = Concentration is between the Minimum Detectable and Minimum Quantifiable Concentrations ND = Not Detected (below the Minimum Detectable Concentration) ( ) = The value which is shown in brackets is the minimum detectable concentration (MDC) for this sample. The MDC is calculated by dividing the analytical Limit of Detection by the air sample volume and is reported as a less than (<) value.									



**Table 11**  
**Total Particulate Concentrations: Personal Breathing-Zone Samples**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Sampling Date	Activity	Sampling Time	Sample Volume	Concentration, mg/m <sup>3</sup>
<b>Conventional Asphalt Paving</b> <b>8/22/95</b>	Paver Operator <sup>a,b</sup>	8:56 am → 3:44 pm	816	ND (<0.02)
	Screed Operator <sup>b</sup>	8:53 am → 3:48 pm	830	0.3
	Screed Operator <sup>b</sup>	8:44 am → 3:40 pm	832	0.06
	Roller Operator (Front) <sup>a</sup>	7:53 am → 3:50 pm	954	0.1
	Roller Operator (Middle) <sup>a</sup>	8:06 am → 4:04 pm	956	0.03
	Roller Operator (Finish) <sup>a</sup>	8:20 am → 3:58 pm	916	0.04
	Laborer <sup>c</sup>	8:40 am → 4:04 pm	888	ND (<0.02)
	State Inspector	7:57 am → 3:37 pm	920	0.04
<b>Conventional Asphalt Paving</b> <b>8/23/95</b>	Paver Operator <sup>a,b</sup>	11:24 am → 3:12 pm <sup>P</sup>	456	Analytical Problem
	Screed Operator <sup>b</sup>	7:05 am → 3:08 pm	964	0.05
	Screed Operator <sup>b</sup>	7:05 am → 3:10 pm	970	0.04
	Roller Operator (Front) <sup>a</sup>	7:10 am → 3:17 pm	976	0.02
	Roller Operator (Middle) <sup>a</sup>	7:13 am → 3:27 pm <sup>‡</sup>	970	0.04
	Roller Operator (Finish) <sup>a</sup>	7:10 am → 3:29 pm	998	0.05
	State Inspector	7:57 am → 3:06 pm	858	0.09
<b>CRM Asphalt Paving</b> <b>7/13/95</b>	Paver Operator	6:15 am → 5:21 pm <sup>†</sup>	1182	0.13
	Screed Operator	6:16 am → 5:09 pm <sup>†</sup>	1136	0.18
	Screed Operator	6:16 am → 5:05 pm <sup>†</sup>	1144	0.19
	Roller Operator (Rear)	6:23 am → 4:58 pm	1116	0.12
	Roller Operator (Front)	6:20 am → 5:00 pm	1126	0.18
	Laborer	6:57 am → 11:37 pm <sup>‡</sup>	402	0.67
	Laborer	6:16 am → 11:37 pm <sup>‡</sup>	500	0.56
	State Inspector	6:24 am → 3:51 pm	988	0.31
<b>CRM Asphalt Paving</b> <b>7/14/95</b>	Paver Operator	6:58 am → 3:35 pm <sup>†</sup>	838	0.08
	Screed Operator	6:58 am → 3:37 pm <sup>†</sup>	421	ND (<0.02)
	Screed Operator	6:58 am → 3:40 pm <sup>†</sup>	846	0.18
	Roller Operator (Rear)	7:05 am → 3:48 pm	436	0.14
	Roller Operator (Front)	6:57 am → 3:39 pm	860	0.30
	Laborer	6:58 am → 3:38 pm	844	0.21
	State Inspector	7:00 am → 3:33 pm	784	0.20

† Pump turned off during periods when no paving was being performed.  
‡ Sampling period ended because employee was reassigned to other duties away from paving site.  
Analytical problem: The sample filter tore during the gravimetric analysis, resulting in a negative weight.  
P Sampling pump failed on first sample (between 7:07 am and 11:24 am). New pump and filter started at 11:24 am. Results from the first sample not reported because sampling volume was unknown.  
a At the request of the employee, the area sample was positioned on (or near) the seat used by the operator. This location, however, was very near the breathing-zone of the worker.  
b The screed operators switched left and right positions throughout the work day.  
c This laborer was moving traffic cones and often was not near the paver.  
d This average sample volume does not include the partial sample volume for the paver sample of 8/23/95.

**Table 12**  
**Polycyclic Aromatic Compounds (PACs) Concentrations: Personal Breathing-Zone Samples**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Sampling Date	Activity	Sampling Time (minutes)	Sample Volume (Liters)	Air Concentration, micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ )			
				PACs <sub>370</sub>	PACs <sub>400</sub>	SulCom	Benzothiazole
8/22/95	Paver OperatorP	408	816	2.8	0.47	ND (<1.3)	ND (<1.3)
	Screed Operator♦	415	830	0.65	0.12	ND (<1.3)	ND (<1.3)
	Screed Operator♦	416	832	0.67	0.12	ND (<1.3)	ND (<1.3)
	Roller Operator (Front)	477	954	Trace	ND	ND (<1.2)	ND (<1.2)
	Roller Operator (Middle)	333	666	Trace	ND	ND (<1.7)	ND (<1.7)
	Roller Operator (Rear)	458	916	0.2	Trace	ND (<1.2)	ND (<1.2)
	Laborer	444	888	0.54	0.11	ND (<1.2)	ND (<1.2)
	State Inspector	460	920	0.37	0.09	ND (<1.2)	ND (<1.2)
8/23/95	Paver OperatorP	486	972	1.1	0.16	ND (<1.1)	ND (<1.1)
	Screed Operator♦	207†	414	0.63	0.1	ND (<2.7)	ND (<2.7)
		253†	506	1.2	0.28	ND (<2.2)	ND (<2.2)
	Screed Operator♦	485	970	1.1	0.12	ND (<1.1)	ND (<1.1)
	Roller Operator (Front)	488	976	0.08	Trace	ND (<1.1)	ND (<1.1)
	Roller Operator (Middle)	494	988	Trace	ND	ND (<1.1)	ND (<1.1)
	Roller Operator (Finish)	499	998	Trace	ND	ND (<1.1)	ND (<1.1)
State Inspector	300	600	0.3	0.07	ND (<1.1)	ND (<1.1)	
7/13/95	Paver Operator	591	1182	6.9	0.88	8.9	33
	Screed Operator	522	1044	8.2	0.92	0.96	33
	Screed Operator	493	986	6.4	0.79	ND (<1.5)	30
	Roller Operator (Front)	510	1020	1.9	0.22	ND (<1.5)	5.1
	Roller Operator (Rear)	508	1016	0.87	0.10	ND (<1.5)	2.0
	Laborer	250	500	3.2	0.52	135	19
	Laborer	69✓	138	4.2	0.58	ND (<11)	38
	State Inspector	466	932	2.9	0.36	ND (<1.6)	15
7/14/95	Paver Operator	419	838	11	1.5	16	58
	Screed Operator	421	842	6.8	0.81	6.1	41
	Screed Operator	423	846	8.7	0.71	ND (<1.8)	34
	Roller Operator (Front)	430	860	1.4	0.16	ND (<1.7)	5.1
	Roller Operator (Rear)	218	436	1.8	0.18	ND (<3.4)	7.8
	Laborer	422	844	3.1	0.43	ND (<1.8)	19
	State Inspector	392	784	3.0	0.36	ND (<1.9)	18

SulCom = Other sulfur-containing compounds  
 PAC<sub>370</sub> = PACs @ 370 nanometers, including vapor & particulate  
 Trace = Concentration is between the Minimum Detectable and Minimum Quantifiable Concentrations  
 ( ) = The value which is shown in brackets is the minimum detectable concentration (MDC) for this sample. The MDC is calculated by dividing the analytical Limit of Detection by the air sample volume and is reported as a less than (<) value.  
 ✓ = The worker was reassigned to other duties away from the paver, so the sampling was discontinued after 69 minutes  
 P = At the request of the paver operator, the sampler was positioned at his operating station while he worked  
 ♦ = The screed operators switched sides throughout the workday  
 † = Two personal breathing-zone air samples were collected on this screed operator on 8/23/95  
 Note: The front roller was nearest the paver. The middle and finish rollers worked farther away from the paver vehicle.

**Table 13**  
**Number of Acute Symptom Questionnaires Completed by Workers**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Work Group		Acute questionnaires actually completed / the number of questionnaires that could be potentially completed			
		7/13/95 Day 1 CRM Asphalt	7/14/95 Day 2 CRM Asphalt	8/22/95 Day 3 Conventional Asphalt	8/23/95 Day 4 Conventional Asphalt
Pavers (n= 7)*		35/35	35/35	27/35	29/35
Non-pavers		19/20**	20/20**	34/35***	34/35***
Paving Period Totals	Pavers	70/70		56/70	
	Non-pavers	39/40**		68/70***	
* = The same seven pavers participated all four survey days, except for one paver who did not participate on day 3 ** = The same four non-pavers participated on survey days 1 & 2 (n=4) *** = Two non-pavers from study days 1 & 2 plus five new non-pavers participated in the study on days 3 & 4 (n=7)					

**Table 14**  
**Number of Workers Reporting Symptoms and Number of Symptom Occurrences by Survey Day**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Symptoms	Work Groups	Number of workers reporting symptoms (Number of symptom occurrences reported)			
		7/13/95 Day 1 CRM Asphalt	7/14/95 Day 2 CRM Asphalt	8/22/95 Day 3 Conventional Asphalt	8/23/95 Day 4 Conventional Asphalt
Dry, itching, or irritated eyes	Pavers	0	0	1 (1)	1 (1)
	Non-pavers	0	0	1 (2)	0
Stuffy, burning, or irritated nose	Pavers	2 (2)	0	0	0
	Non-pavers	0	0	0	0
Sore, dry, scratchy, or irritated throat	Pavers	1 (3)	2 (5)	0	1 (1)
	Non-pavers	0	0	0	0
Skin burning, rash, itching, or irritated	Pavers	1 (1)	1 (1)	0	0
	Non-pavers	0	0	0	0
Bothered by coughing	Pavers	1 (3)	1 (4)	1 (1)	1 (2)
	Non-pavers	0	0	0	0
Chest tightness or shortness of breath	Pavers	0	0	0	0
	Non-pavers	1 (1)	0	0	0
Wheezing or whistling in chest	Pavers	0	0	0	0
	Non-pavers	0	0	0	0
Totals	Pavers*	3 (9)	2 (10)	2 (2)	3 (4)
	Non-pavers	1 (1)**	0**	1 (2)***	0***
* = The same seven pavers participated all four study days, except for one paver who did not participate on day 3 ** = Four non-pavers participated on study days 1 & 2 (n=4) *** = Two non-pavers from study days 1 & 2 plus five new non-pavers participated in the study on days 3 & 4 (n=7)					

**Table 15**  
**Rate of Symptoms Occurrence Per Questionnaire Among Pavers by Survey Day**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Pavers (n=7)*	7/13/95 Day 1 CRM Rubber Asphalt	7/14/95 Day 2 CRM Rubber Asphalt	8/22/95 Day 3 Conventional Asphalt	8/23/95 Day 4 Conventional Asphalt
	Completed Questionnaires	35	35	27
Symptom Occurrences	9	10	2	4
Rate symptom occurrence per questionnaire	0.26	0.29	0.07	0.14
	0.27		0.11	

\* = The same seven pavers participated all four study days, except for one paver who did not participate on day 3

**Table 16**  
**Estimated Hours of Exposure to Asphalt Fume Among Pavers by Job Title and Survey Day**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

Job Title (n= 7)*	Estimated hours exposure to asphalt fume			
	7/13/95 Day 1 CRM Rubber Asphalt	7/14/95 Day 2 CRM Rubber Asphalt	8/22/95 Day 3 Conventional Asphalt	8/23/95 Day 4 Conventional Asphalt
Paver Operator	6.0	7.75	(not determined)	10.0
Screed Operator	5.5	7.75	7.5	10.0
Screed Operator	5.5	7.75	2.0	10.0
Laborer	4.0	7.5	7.75	7.0
Breakdown Roller	6.0	7.75	8.0	9.75
Roller Operator	4.5	7.75	8.25	9.25
State Inspector	5.0	7.5	7.25	9.25
<b>Daily Total Hours (Average)</b>	36.5 (5.2)	53.75 (7.7)	40.75 (6.8)	65.25 (9.3)
<b>Total Hours by Asphalt Paving Material (Average)</b>	90.25 (6.5)		106 (8.2)	

\* = The same seven pavers participated all four study days, except for one paver who did not participate on day 3

**Table 17**  
**Rate of Symptoms Per Hour of Exposure Among Pavers by Survey Day**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

<b>Pavers (n=7)*</b>	<b>7/13/95 Day 1 CRM Rubber Asphalt</b>	<b>7/14/95 Day 2 CRM Rubber Asphalt</b>	<b>8/22/95 Day 3 Conventional Asphalt</b>	<b>8/23/95 Day 4 Conventional Asphalt</b>
<b>Estimated Exposure to Asphalt (total hours)</b>	36.5	53.75	40.75	65.25
<b>Number Symptom Occurrences</b>	9	10	2	4
<b>Rate (symptom occurrence/hr exposure)</b>	0.25	0.19	0.05	0.06
	0.21‡		0.06‡	
<p>* = The same seven pavers participated all four study days, except for one paver who did not participate on day 3.            ‡ = Average rate (over two days) of symptom occurrence per hour of exposure.</p>				

**Table 18**  
**Summary of Area Concentrations of Air Contaminants**  
**Paving Company: Koester Equipment, Evansville, Indiana (HETA 95-0307)**

	Analyte	TWA Concentration, expressed in micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ )							
		8/22/95 Conventional	8/23/95 Conventional	7/13/95 CRM	7/14/95 CRM				
<b>Paver Hopper</b>	Total Particulate	220	180	240	200				
	Respirable Particulate	30	110	160	180				
	Benzene Soluble Particulate	ND	Trace	60	100				
	PAC <sub>S370</sub> (vapor & particulate)	45◆	35	143	41				
	PAC <sub>S400</sub> (vapor & particulate)	5.1◆	4.8	6.4	6.1				
	Benzothiazole	ND◆	ND	31	89				
	Other Sulfur Compounds	ND◆	97	51	84				
	Total Hydrocarbons with a retention time < toluene	Trace	30	ND	ND				
Total Hydrocarbons with a retention time > toluene	980	1200	500	380					
<b>Air Sample Position at Screenshot →</b>		Left	Right	Left	Right	Left	Right	Left	Right
<b>Paver Screed</b>	Total Particulate	250	150	90	130	1000	1000	1200	1100
	Respirable Particulate	170	40	90	40	580	510	330	380
	Benzene Soluble Particulate	Trace	Trace	Trace	ND	560	400	980	700
	PAC <sub>S370</sub> (vapor & particulate)	22	14	49	19	143	153	216	84
	PAC <sub>S400</sub> (vapor & particulate)	2.9	1.9	6.0	2.4	22	26	35	16
	Benzothiazole	ND	Trace	ND	ND	61	67	127	125
	Other Sulfur Compounds	70	70	105	47	255	296	792	164
Total Hydrocarbons with a retention time < toluene	Trace	ND	30	Trace	40	30	ND	50	
Total Hydrocarbons with a retention time > toluene	590	240	960	470	2100	1700	Trace	3800	
<b>Highway Backgnd.</b>	Total Particulate†	100	50	130	90				
	Respirable Particulate	ND	ND	140‡	ND				

† = Average of two or more highway background air samples.

‡ = This sample should be considered suspect since it exceed the total particulate sample result.

PAC<sub>370</sub> = Polyaromatic compound measured with 370 nanometer wavelength detector.

PAC<sub>400</sub> = Polyaromatic compound measured with 400 nanometer wavelength detector.

ND = Not Detected (below the Minimum Detectable Concentration).

Trace = Concentration is between the Minimum Detectable and Minimum Quantifiable Concentration.

Note = Highway background concentrations for benzene soluble fraction, PAC<sub>370</sub> and PAC<sub>400</sub> are not reported in this summary table. Please refer to the previous tables for these concentrations.

◆ = Sampling pump failed twice during the workday. Concentration based on estimated sample volume.