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PREFACE

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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 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:

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

The protocol allows for up to eight individual site evaluations in different 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 Boston, Massachusetts, during asphalt pavement construction at two sites: Interstate 95 (near Foxborough, Massachusetts) and State Route 138 (in Dighton, Massachusetts). 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 Massachusetts project.

On the evenings of June 25 and 27, 1997, approximately 2,540 metric tons of CRM asphalt (rubber content approximately 16% of the asphalt binder by weight) were applied by Bardon–Trimount along the southbound lanes of Interstate 95. On July 22 and 23, 1997, approximately 1,930 metric tons of conventional asphalt were placed by most of the same workers along State Route 138.

The workplace exposure and health assessment were performed during all four paving days. Among the differences between the two paving sites included the following: (1) the CRM paving was performed at night along a heavily traveled six–lane highway while the conventional paving was conducted during the day along a two–lane rural road; and 2) the CRM hot mix asphalt laydown temperature was approximately 14°C hotter than the conventional asphalt laydown temperature (177°C versus 163°C). 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 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. 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 volatile 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_2S), and sulfur dioxide (SO_2). Finally, bulk air samples of asphalt fume were collected at the asphalt cement storage tank located at the hot mix asphalt plant and above the screed auger on the paving vehicle and submitted for mutagenicity testing.

Area air sample results revealed that concentrations of TP, respirable particulate, and BSF varied between sampling locations and across survey days, but were consistently higher during the CRM asphalt paving periods than during conventional asphalt paving periods. For example, TP concentrations at the screed auger ranged from 6 to 12 milligrams per cubic meter (mg/m^3) during CRM asphalt paving, compared to 1.4 to 1.9 mg/m^3 during conventional paving. Concentrations of respirable particulate during CRM asphalt ranged from 2.5 to 4.8 mg/m^3, compared to 0.44 to 0.77 mg/m^3 during conventional asphalt paving. BSF concentrations during CRM and conventional asphalt paving ranged from 5.8 to 10 mg/m^3 and 1.2 to 1.6 mg/m^3, respectively.

Higher area air concentrations of PACs were measured during CRM than during conventional asphalt paving. The smaller ring number PACs (PAC$_{370}$) are believed to be associated with more irritative effects, whereas more concern exists for suspect carcinogenicity of the 4–7 ring PACs (PAC_{400}). In every sample, the PAC_{370} concentration was greater than the corresponding PAC_{400} concentration, implying that the 2–3 ring PACs may be more abundant. PAC_{370} concentrations during CRM paving ranged from 7.0 to 2,832 $\mu g/m^3$; during conventional paving they ranged from not detected (<0.06) to 486 $\mu g/m^3$. Benzothiazole was detected only during CRM asphalt paving. Occupational exposure limits for total PACs and other sulfur compounds (as a class), or to benzothiazole, do not presently exist.

Over 50 volatile organic compounds (VOCs) were detected in the asphalt emissions, but only the most significant peaks were analyzed quantitatively. Toluene, xylene, and MIBK were present at concentrations less than 1 part per million (ppm). Total hydrocarbons, quantified as either n–hexane or Stoddard solvent, were below their respective occupational exposure limits. Benzene was detected during CRM asphalt paving in concentrations ranging from 0.051 to 0.77 ppm, suggesting a potential for employee exposure to benzene, especially during CRM asphalt paving. NIOSH classifies benzene as an occupational carcinogen and recommends that exposure be reduced to the lowest feasible concentration.

All PBZ TP exposures were well below the current NIOSH recommended exposure limit (REL) of 5 mg/m^3 (it should be noted that since the NIOSH REL for asphalt fume is based on a 15–minute exposure, the PBZ results from this survey are not be directly comparable since they were collected over a full shift). The TWA–actual PBZ exposures to TP ranged from 0.034 to 0.52 mg/m^3 and from 0.043 to 0.78 mg/m^3 during conventional and CRM asphalt paving, respectively. The BSF results followed a similar pattern, with concentrations consistently higher during CRM asphalt paving than conventional asphalt application. The average BSF concentrations of the jobs in closest proximity to asphalt fume emissions (typically the paver and screed operators, laborers, and mechanics) were approximately twice as high on CRM asphalt paving days than during conventional asphalt paving (0.23 mg/m^3 versus 0.13 mg/m^3, respectively).

PBZ concentrations of PAC_{370} and PAC_{400} and other sulfur–containing compounds were higher during CRM asphalt paving than conventional paving. In every sample, regardless of the type of asphalt being applied, the PAC_{370} concentration was greater than the corresponding PAC_{400} concentration. PAC_{370} concentrations during CRM paving ranged from 2.7 to 466 $\mu g/m^3$; during conventional paving they ranged from 1.2 to 191 $\mu g/m^3$. Benzothiazole was detected only during CRM asphalt paving operations, ranging up to 108 $\mu g/m^3$.

Time–weighted average CO concentrations ranged from 8 to 24 ppm during CRM paving, with peak values as high as 910 ppm. These results suggest that full–shift CO exposures were approaching the NIOSH REL of 35 ppm (8–hour TWA) and, in some instances, exceeded the NIOSH ceiling limit of 200 ppm. Concentrations of H_2S and SO_2 were well below their respective occupational exposure limits. The noise exposures of 13 pavers evaluated during both CRM and conventional asphalt paving exceeded the NIOSH REL for noise, and 11 of these 13 workers exceeded the OSHA action level for implementing a hearing conservation program. Most of the paving crew did not wear hearing protection devices (HPDs) during this survey.

Six workers with exposure to the asphalt paving operation (pavers) were included in the analysis of the health assessment data. Additionally, eight workers not exposed to hot asphalt fume (non–pavers) were evaluated 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 work site exposures. Serial measurements of peak expiratory flow rate (PEFR) were conducted to evaluate acute changes in lung function in relation to work site exposures. Seven pavers and three non–pavers were excluded from analysis of the health data because they were not available to participate for at least three of the four survey days.

There were no symptom occurrences reported among non–pavers during the first two survey days (CRM asphalt paving), compared with reports of three symptom occurrences (throat irritation, nasal irritation, cough) during the

last two survey days (conventional asphalt paving). Among the six pavers there was a total of 46 symptom occurrences reported over the four survey days. There were 30 symptom occurrences (65%) on the first two survey days (CRM asphalt paving) compared with 16 symptom occurrences (35%) during the last two survey days (conventional asphalt paving). For pavers, the most frequently reported symptoms (as a percentage of occurrences over all four days) were throat irritation (33%), nasal irritation (30%), and eye irritation (28%). Aside from higher reporting of throat irritation during the CRM paving period and nasal symptoms during the conventional paving period, there was no substantial difference in the types and numbers of symptoms reported by pavers between the paving periods. Among pavers, 87% of the symptoms were reported during ongoing or recent exposure to asphalt fumes, and 76% of the symptoms reported were rated as “mild” in severity (the choices were “mild,” “moderate,” or “severe”).

The results of the acute symptom survey revealed that among the pavers, the rate of symptom occurrences per completed questionnaire and the rate of symptom occurrences per self–reported hour of asphalt paving was approximately 90% higher during the CRM asphalt paving period than the conventional asphalt paving period. The observed increase in symptom occurrences was primarily due to increased reporting of throat irritation during the CRM asphalt paving period. While acute irritant symptoms were reported by workers in association with work site exposures, none of the pavers demonstrated significant bronchial lability on any of the survey days.

This study showed that although PBZ exposures to asphalt fume emissions were below current NIOSH RELs, carbon monoxide exposures were approaching the NIOSH REL of 35 ppm (8–hour TWA) and, in some instances, exceeded the NIOSH ceiling limit of 200 ppm. All sampled workers’ noise exposure exceeded the NIOSH REL, and 11 of the 13 employees sampled had exposures that exceeded the OSHA action level for implementing a hearing conservation program. Most of the paving crew were not wearing hearing protection devices (HPDs) during this survey. For the area air samples measuring asphalt fume, concentrations of TP, respirable particulate, BSF, PACs, and other sulfur–containing compounds (except benzothiazole) were higher during CRM asphalt paving than during conventional paving. The PBZ concentrations of TP, BSF, total PACs, and other sulfur–containing compounds (except benzothiazole), while not as high as those in the area samples, were generally higher during the CRM asphalt paving period. Although the higher symptom rates associated with CRM asphalt paving coincide 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 evaluation makes further interpretation of this association difficult. 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.

Keywords: SIC 1611 (Highway and Street Construction), asphalt fume, bitumen, crumb rubber modified, 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.

TABLE OF CONTENTS

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 and sizes of the aggregate materials to the amount of asphalt cement to obtain the appropriate pavement properties (flexibility, drainage, durability, etc.).

The purpose of a 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, tackman, 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 June 25 and 27, and continuing on July 22 and 23, 1997, NIOSH investigators conducted a study near Boston, Massachusetts, during asphalt pavement construction by Bardon–Trimount. Paving sites were located along the southbound lanes of Interstate 95 (near Foxborough, Massachusetts) and along two roads in Dighton, Massachusetts (State Route 138 and Elm Street). Jobs evaluated in this survey included paver operator, screed operators, laborers (their activities included, among other tasks, occasionally operating the screed auger), roller operators, and traffic control personnel. Unlike previous NIOSH/FHWA asphalt surveys, however, several members of the paving crew changed between paving locations.

During this survey, the same petroleum crude source was used for 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"). However, because of production requirements, different Bardon–Trimount HMA plants were used to supply paving material for the June and July paving projects. The CRM asphalt was placed on June 25 and 27, while the conventional asphalt was used on July 22 and 23. Because of state requirements to minimize traffic congestion, all paving on Interstate 95 was required to be performed at night (between approximately 8:00 p.m. and 4:30 a.m.). During this time two lanes of traffic would be diverted to permit paving on the remaining traffic lanes, breakdown lane, or shoulder. In contrast, the conventional asphalt paving was performed during the day on two–lane roads (either State Route 138 or Elm St.) located in Dighton, Massachusetts.

Table 1 contains a summary of the paving activities and equipment used at the two sites. Both the CRM and conventional paving projects used a 19–millimeter (mm) maximum grade hot mix asphalt. The CRM asphalt was used on a dense binder course for a section of I–95; the conventional asphalt was a modified top mix. The crude supplier was Bardon–Trimount, Newington, New Hampshire, and the granulated rubber was manufactured by the NRB Materials Company, Chambersburg, Pennsylvania. A viscosity graded asphalt cement, AC–20, was used for the conventional asphalt, while an AC–10 was used in the CRM asphalt paving. The CRM asphalt design mix allowed up to 16% rubber (total weight of rubber by the total weight of the asphalt/rubber blend).

As previously mentioned, two different HMA plants (both operated by Bardon–Trimount, however) were used during this construction project. The plant which supplied the CRM asphalt was located in Tauton, Massachusetts, approximately 20 minutes away from the I–95 paving site. The HMA plant (and quarry) which supplied conventional paving material for the Dighton, Massachusetts site was located in Wretham, Massachusetts, about 45 minutes from the paving site. During both the conventional and CRM asphalt paving, the HMA was hauled to the paving site by tri–axle dump trucks (average capacity ranged from approximately 22 to 31 metric tons). About 2,540 metric tons of CRM asphalt were applied on June 25 and 27, compared to 1,931 metric tons of conventional asphalt placed on July 22 and 23. The approximate laydown temperatures for the conventional and CRM asphalt mixes were 141°C (285°F) and 153°C (307°F), respectively.

The CRM asphalt was used to construct a dense binder course for a section of I–95 (all three traffic lanes, plus the shoulder and breakdown lanes were paved). The conventional asphalt was used for a surface friction course on a two lane sections of both State Route 138 and Elm Street in Dighton, Massachusetts. The uncompacted depth of both the conventional asphalt and CRM asphalt overlays was approximately 6.4 cm (2.5 inches); the width of the paving varied from approximately 3.4 to 4.6 meters (11 to 15 feet).

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 particulate (TP) and the benzene soluble particulate fraction (BSF). 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 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 situation, new or modified sampling and analytical methods were developed and included in this study. For example, 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, and methyl isobutyl ketone [MIBK]) and total hydrocarbons (quantified as either n–hexane or as 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 particles which were respirable. 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 to allow comparison 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 15–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 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, collected next to an open vent on the asphalt cement storage tank at the HMA plant and above the screed auger on the paver, 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 Samples

Air Samples

Personal breathing–zone (PBZ) monitoring was conducted on most of the members of the paving crew throughout the four survey days. Full–shift PBZ samples were collected for the following compounds: TP (along with the benzene soluble fraction), total PACs, and other sulfur–containing compounds (including benzothiazole).

Noise Dosimetry

To continuously monitor noise exposures, Quest® Electronics Model M–27 Noise Logging Dosimeters were worn by paver and roller operators during the work shift. Since these workers remained seated for most of their work shift to operate the paving equipment, the noise dosimeter was attached to the employee's seat and the microphone attached to the employee's shoulder.[a] During periods when the workers left the paver or roller for short breaks, the microphone was clipped to the seat. Due to safety and comfort concerns, noise dosimeters were not used on the screed operators, laborers, or other members of the paving crew who were already wearing two air sampling pumps.

At the end of workshift, the dosimeters were removed and paused to stop data collection. The information was downloaded to a personal computer with Quest® Electronics Metrosoft computer software for interpretation. The dosimeters were calibrated before the work shift according to the manufacturer's instructions.

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 is the *draft* NIOSH Sampling and Analytical Method No. 5042 for total particulate and benzene soluble fraction (asphalt fume). Appendix C is the NIOSH Sampling and Analytical Method No. 5040 for elemental carbon.

MEDICAL EVALUATION DESIGN

On June 24, 1997, NIOSH investigators recruited workers to participate in the health assessment, which included a general health and occupational

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[a] A personal noise sample is typically obtained by attaching the dosimeter to the employee's belt with the microphone fastened to the work uniform (facing forward) at the approximate mid–point between the ear and the outside of the worker's shoulder.

history questionnaire, serial acute symptom questionnaires, and serial peak expiratory flow rate (PEFR) testing. The 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.

Over the course of the survey, NIOSH investigators recruited a total of 13 workers with exposure to the asphalt paving operation (pavers) to participate in the study. Initially, all ten pavers at the site were recruited to participate in the study for all four days; however, four of the ten workers were not available for the last two survey days due to assignment to other job sites, resulting in the recruitment of three additional pavers for this period. Additionally, for comparison purposes 11 workers employed at the same construction site, but not in proximity to the asphalt paving operation (non–pavers), were recruited to participate in the health assessment.

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.

The 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. The primary sources of evaluation criteria for the workplace are NIOSH criteria documents and recommended exposure limits (RELs) [NIOSH 1992], 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®) [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 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 TWA. Personal exposures can be expressed in parts per million (ppm), milligrams per cubic meter (mg/m^3), or micrograms per cubic meter ($\mu g/m^3$). 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 becomes 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^3 (as a 15–minute ceiling limit) for asphalt fumes, measured as a 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^3 (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® for asphalt fumes is 5 mg/m^3 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.

Occupational Noise Exposure

Noise–induced loss of hearing is an irreversible, sensorineural condition that progresses with exposure. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise–induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically [Ward 1986]. While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, noise–induced hearing loss is insidious. Typically, it begins to develop at 4000 or 6000 hertz (Hz) (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions. Although the primary frequencies of human speech range from 200 Hz to 2000 Hz, research has shown that the consonant sounds, which enable people to distinguish words such as "fish" from "fist," have still higher frequency components [Suter 1978].

The A–weighted decibel [dB(A)] is the preferred unit for measuring sound levels to assess worker noise exposures. The dB(A) scale is weighted to approximate the sensory response of the human ear to sound frequencies near the threshold of hearing. The decibel unit is dimensionless, and represents the logarithmic relationship of the measured sound pressure level to an arbitrary reference sound pressure (20 micropascals, the normal threshold of human hearing at a frequency of 1000 Hz). Decibel units are used because of the very large range of sound pressure levels which are audible to the human ear. Because the dB(A) scale is logarithmic, increases of 3 dBA, 10 dBA, and 20 dBA represent a doubling, tenfold increase, and 100–fold increase of sound energy, respectively. It should be noted that noise exposures expressed in decibels cannot be averaged by taking the simple arithmetic mean.

The OSHA standard for occupational exposure to noise (29 CFR 1910.95) [OSHA 1993] specifies a maximum PEL of 90 dB(A) for a duration of eight hours per day. The regulation, in calculating the PEL, uses a 5 dB time/intensity trading relationship, or exchange rate. This means that a person may be exposed to noise levels of 95 dB(A) for no more than 4 hours, to 100 dB(A) for 2 hours, etc. Conversely, up to 16 hours exposure to 85 dB(A) is allowed by this exchange rate. NIOSH, in its Criteria for a Recommended Standard, [NIOSH 1972] proposed a REL of 85 dB(A) for 8 hours, 5 dB less than the OSHA standard. The NIOSH 1972 criteria document also used a 5 dB time/intensity trading relationship in calculating exposure limits. However, in 1995, NIOSH changed its official recommendation for an exchange rate of 5 dB to 3 dB [Niemeier 1995]. The ACGIH also changed its TLV in 1994 to a more protective 85 dB(A) for an 8–hour exposure, with the stipulation that a 3 dB exchange rate be used to calculate time–varying noise exposures [ACGIH 1996]. Thus, a worker can be exposed to 85 dB(A) for 8 hours, but to no more than 88 dB(A) for 4 hours or 91 dB(A) for 2 hours.

The duration and sound level intensities can be combined in order to calculate a worker's daily noise dose according to the formula:

$$\text{Dose} = 100 \text{ X } (C_1/T_1 + C_2/T_2 + ... + C_n/T_n),$$

where C_n indicates the total time of exposure at a specific noise level and T_n indicates the reference duration for that level as given in Table G–16a of the OSHA noise regulation [OSHA 1993]. During any 24–hour period, a worker is allowed up to 100% of his daily noise dose. Doses greater than 100% are in excess of the OSHA PEL.

The OSHA regulation has an additional action level (AL) of 85 dB(A); an employer shall administer a continuing, effective hearing conservation program when the TWA value exceeds the AL. The program must include monitoring, employee notification, observation, audiometric testing, hearing protectors, training, and recordkeeping. All of these requirements are included in 29 CFR 1910.95, paragraphs (c) through (o).

Finally, the OSHA noise standard states that when workers are exposed to noise levels in excess of the OSHA PEL of 90 dB(A), feasible engineering or administrative controls shall be implemented to reduce the workers' exposure levels. However, in 1983, a compliance memorandum (CPL 2–2.35) directed OSHA compliance officers not to cite employers for lack of engineering controls until workers' TWA levels exceed 100 dB(A), so long as the company has an effective hearing conservation program in place. Even in TWA levels in excess of 100 dB(A), compliance officers are to use their discretion in issuing fines for lack of engineering controls.

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. Unfortunately, neither the TAMS weather station nor the heat stress meter arrived in time to collect temperature, humidity, wind direction, and wind speed information during the CRM asphalt paving on June 25 and 27, 1997. Our subjective weather evaluation of these evenings were mild winds (predominately from the north), with temperatures falling from 20 to 21°C (low–70's°F) to 17 to 18°C (mid–to upper–60's°F).

Perhaps the most obvious difference between the conventional and CRM asphalt paving periods was that the nighttime paving temperatures were cooler than those measured during the daytime paving.

Other potentially significant differences were the estimated traffic density and the speed of traffic through the construction zone. During the CRM asphalt paving, traffic density was heavy and diverted to the lanes immediately adjacent to the ones being paved. In addition, traffic speeds were approximately 45 to 50 miles per hour through the construction zone. In contrast, most vehicular traffic was detoured around the two conventional asphalt paving zones in Dighton, Massachusetts.

Wind speed and direction can be important factors that influence air sampling results. As shown in Table 4, the wind direction was generally from the north on all four survey days and wind speed did not vary much throughout the day. Some of the paving crew, especially the paver operator and the screed operators/laborers, were often downwind from the asphalt fume emissions. In contrast, all of the roller operators generally remained on the upwind side of the asphalt fume emissions.

Process Information

The average production rate (number of tons of asphalt paved per hour) was approximately 60% higher during CRM asphalt paving than during conventional paving (average of 115 metric tons/hour for conventional paving and 190 metric tons/hour for CRM paving). The proximity of the HMA plant (about a 15 to 20 mintue commute) to the I–95 CRM asphalt paving site resulted in nearly continuous paving nights with very little down time. The CRM asphalt delivery trucks also encountered less traffic during the evening hours, further improving delivery of material to the paving site. In contrast, the traveling time between the HMA plant suppling the conventional asphalt and the Dighton, Massachusetts, paving site was approximately 45 to 60 minutes, resulting in an inconsistent paving rate.

Area Air Samples

Total Particulate and Respirable Particulate

Tables 5 and 6 provide the results for the total and respirable particulate concentrations, respectively. At the paver screed, the TP concentrations ranged from 1.4 to 1.9 mg/m^3 and from 6 to 12 mg/m^3 for conventional and CRM asphalt paving, respectively. All of the TP concentrations measured during conventional asphalt paving were below the NIOSH REL of 5 mg/m^3, while all TP concentrations measured during CRM paving exceeded this limit.[b] The daily average TP background concentrations measured during this survey ranged from 0.03 to 0.07 mg/m^3.

The highest respirable particulate concentrations (range 2.5 to 4.8 mg/m^3) were obtained during CRM asphalt paving. The respirable particulate concentrations collected during conventional asphalt paving ranged from 0.44 to 0.77 mg/m^3. The background respirable particulate concentrations ranged from not detected (<0.03 mg/m^3) to 0.11 mg/m^3.[c]

Benzene Soluble Particulate Fraction

As summarized in Table 5, BSF concentrations at the paver screed ranged from 1.2 to 1.6 mg/m^3 during conventional paving and from 5.8 to 10 mg/m^3 during CRM asphalt paving. The much higher BSF concentrations measured during CRM asphalt paving are consistent with the higher TP concentrations which were also measured during CRM paving. Presently, there are no NIOSH or OSHA occupational exposure limits for the benzene soluble particulate fraction of asphalt fume.

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[b] The NIOSH REL for asphalt fume is for a 15–minute exposure. All of the area and PBZ air samples in this study were collected over a full–shift and thus are not directly comparable to the NIOSH REL.

[c] One background sample for respirable particulate was 0.88 mg/m^3. This concentration is considered suspect since it is 8 to 12 times higher than those in other background samples for respirable particulate collected in this study.

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 prevents quantitation of individual polynuclear aromatic hydrocarbons (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 7 summarizes the total PAC area concentrations collected at emission and background locations. Much higher concentrations of PACs were measured during CRM than during conventional asphalt paving. The concentration of total PAC_{370} at the paver screed ranged from not detected (<0.06) to 486 $\mu g/m^3$ for conventional and from 1,853 to 2,832 $\mu g/m^3$ for CRM asphalt. The total PAC_{400} concentrations from these same samples followed a similar pattern, ranging from not detected (<0.06) to 97 and from 130 to 279 $\mu g/m^3$, respectively, for conventional and CRM asphalt paving. In every sample, the PAC_{370} concentration was greater than the corresponding PAC_{400} concentration, 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 limits for total PACs, as a class, do not currently exist.

Table 7 also presents the concentrations of benzothiazole and other sulfur compounds 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 not detected [ND, minimum detectable concentration <0.06 $\mu g/m^3$] during conventional asphalt paving. In contrast, benzothiazole concentrations during CRM asphalt paving were much higher, ranging from 81 to 233 $\mu g/m^3$, suggesting that the crumb rubber was the sole source of the benzothiazole.

Table 7 also presents the sample results collected at the paver screed for other sulfur–containing compounds. Lower concentrations of sulfur compounds were measured during conventional asphalt paving (range 50 to 106 $\mu g/m^3$) than during CRM asphalt paving (range 112 to 295 $\mu g/m^3$). The average concentration of sulfur compounds over the screed auger during conventional asphalt paving was 87 $\mu g/m^3$; the average during CRM asphalt paving was over twice as high (205 $\mu g/m^3$).

Elemental and Organic Carbon

Elemental and organic carbon analytical results are provided in Table 8. All of the air samples collected for EC above the screed auger on the paver vehicle had concentrations above the background levels. The EC:TC ratio, however, ranged from 0.7% to 3.1% above the screed auger. Since diesel exhaust has been reported to contain EC levels between 60 to 80% of the TC [Blade et al. 1989], the relatively low EC:TC ratios measured in this survey imply that diesel exhaust was not substantially contributing to the air sampling results.

Volatile Organic Compounds (VOCs)

Table 9 summarizes the predominant VOC concentrations detected during conventional CRM asphalt paving periods. The qualitative GC/MS analysis identified over 50 VOCs; however, only the most significant peaks (benzene, toluene, xylene, MIBK, and total hydrocarbons) were quantitatively analyzed by GC/FID. Although concentrations were measured during CRM asphalt paving, the quantities of VOCs detected at emission sources during both types of paving were orders of magnitude below their respective occupational exposure limits published by NIOSH, OSHA, or ACGIH. Total hydrocarbons quantified as n–hexane ranged in concentration from 1.3 to 16 mg/m^3, and from 15 to 224 mg/m^3 when quantified as Stoddard solvent. Although the average total hydrocarbon concentrations were approximately 4 to 5 times higher during CRM asphalt paving than during conventional paving, all concentrations were still below occupational exposure limits for either n–hexane or Stoddard solvent.

During conventional asphalt paving, benzene was detected at, or just above, the minimum quantifiable concentration (0.01 ppm). However, during CRM asphalt paving, benzene was present in higher concentrations, ranging from 0.051 to 0.77 ppm. Although these area samples were collected at the *source* of emission, and employees are not at these locations for long durations, these data suggest that the potential exists for employee exposure to benzene, especially during CRM asphalt paving. NIOSH classifies benzene as an occupational carcinogen and recommends that exposure be reduced to the lowest feasible concentration. The OSHA PEL for benzene is an 8–hour TWA of 1 ppm.

Hydrogen Sulfide (H_2S), Sulfur Dioxide (SO_2), and Carbon Monoxide (CO)

Using direct reading instrumentation, concentrations of H_2S and SO_2 were not detected during either CRM or conventional asphalt paving.

Personal Samples

Air Samples

Table 10 presents the PBZ results for TP and BSF monitoring during conventional and CRM paving operations. All of the PBZ TP exposures were well below the criterion of 5 mg/m^3 currently proposed by NIOSH for asphalt fume exposure.[d] The TWA–actual PBZ exposure to TP ranged from 0.034 to 0.52 mg/m^3 and from 0.043 to 0.78 mg/m^3 during conventional and CRM asphalt paving, respectively. As expected, the average TP concentrations measured on the jobs in closest proximity to fume emissions from either the paver or the asphalt delivery trucks (typically the paver and screed operators, laborers, and mechanics) were among the highest exposures, averaging 0.26 mg/m^3 on conventional asphalt days and 0.47 mg/m^3 on CRM asphalt paving days. Although TP concentrations appeared to be consistently higher during CRM asphalt paving than during conventional asphalt paving, a definite conclusion regarding this difference cannot be made due to the limited number of PBZ samples.

The BSF results followed a similar pattern as seen for the TP samples, with PBZ concentrations consistently higher during CRM asphalt paving as compared to conventional asphalt application. For example, the average BSF concentrations for the jobs in closest proximity to fume emissions from either the paver or the asphalt delivery trucks (paver and screed operator, laborers, and mechanics) were approximately twice as high on CRM asphalt paving days than during conventional asphalt paving (0.23 mg/m^3 versus 0.13 mg/m^3, respectively).

Table 11 contains the PBZ results for PACs, benzothiazole, and other sulfur compounds. In every sample, regardless of the type of asphalt being applied, the PAC_{370} concentration was greater than the corresponding PAC_{400} concentration, implying that the 2–3 ring PACs may be more abundant. Although PAC_{370} concentrations varied daily, they were generally higher during CRM paving (range: 2.7 to 466 µg/m^3) than during conventional paving (range: 1.2 to 191 µg/m^3) paving.

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[d] The NIOSH REL for asphalt fume is for a 15–minute exposure. All of the area and PBZ air samples in this study were collected over a full–shift and thus are not directly comparable to the NIOSH REL.

Benzothiazole was detected only during CRM asphalt paving, ranging up to 108 $\mu g/m^3$. This was anticipated since benzothiazole is present in rubber tires. PBZ exposures to other sulfur–containing compounds during conventional and CRM asphalt paving ranged from <0.05 $\mu g/m^3$ to 2 $\mu g/m^3$ and from <0.06 $\mu g/m^3$ to 13 $\mu g/m^3$, respectively.

Since gasoline–powered generators were used on the paver vehicle and rollers for the CRM night paving, PBZ samples for CO were collected using dosimeters. As shown in Table 12, TWA exposures to CO ranged from 8 to 24 ppm during CRM paving, with peak values as high as 910 ppm. Although some of the CO may have resulted from cigarette smoke, these results demonstrate that full–shift CO exposures approached the NIOSH REL of 35 ppm (8–hour TWA) and exceeded the ceiling limit of 200 ppm.

Noise Dosimetry

Table 13 summarizes the noise exposures measured on selected members of the paving crew during both CRM and conventional asphalt paving. All sampled workers' noise exposure exceeded the NIOSH REL, and 11 of the 13 employees sampled had exposures that exceeded the OSHA action level for implementing a hearing conservation program. Most of the paving crew were not wearing hearing protection devices (HPDs) during this survey.

MEDICAL RESULTS

Of the 11 non–pavers that participated, only eight workers were included in the analysis of the health assessment data. Three non–pavers (two traffic controllers, one laborer) were excluded because they were not available to participate for at least three of the four survey days (due to assignment to other job sites) during the course of the survey. Of the thirteen pavers that participated for at least one day over the course of the study, only six were ultimately included in the analysis of the health assessment data. Seven pavers (four roller operators, two paver operators, one mechanic) were excluded from the analysis because they were not available to participate (due to assignment to other job sites) during both the CRM and conventional phases of asphalt paving (available less than three days). All the following results pertain only to the eight non–pavers and six pavers for whom adequate data were available.

The jobs of the eight non–pavers included four laborers, one project supervisor, one foreman, one traffic controller, and one office engineer, while the six pavers included one screed operator, one paving foreman (who also worked the screed), three rakers (one of whom occasionally worked the screed and another of whom frequently worked as a dumpman), and one roller operator.

Seven of the eight non–pavers were male, and the average age of this group was 36 years (range 25–52 years). All six pavers were male and the average age of the group was 40 years (range 31–51 years). Five of the non–pavers currently smoked cigarettes (four smoked during work), two never smoked, and one was a former smoker. Four of the pavers currently smoked cigarettes (all smoked during work), and two had never smoked.

The number of acute symptom questionnaires completed (i.e., the number of opportunities a worker had to report a health symptom) varied among the non–pavers and pavers (Table 14). For the non–pavers, a maximum of 40 (eight workers times five questionnaires/day) questionnaires could have been completed during each survey day. The non–pavers completed 64 (80%) questionnaires during the first two study days and 60 (75%) during the last two study days. For the pavers, a maximum of 30 (six workers times five questionnaires/day) could have been completed each survey day. During the first two study days the pavers completed 53 (88%) questionnaires; during the last two days the pavers completed 55 (92%).

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 15 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. There were no symptom occurrences reported among non–pavers during the first two survey days (CRM asphalt paving), compared with reports of three symptom occurrences (throat irritation, nasal irritation, cough) during the last two survey days (conventional asphalt paving). Among the six pavers there was a total of 46 symptom occurrences reported over the four survey days. There were 30 symptom occurrences (65%) on the first two survey days (CRM asphalt paving) compared with 16 symptom occurrences (35%) during the last two survey days (conventional asphalt paving). For pavers, the most frequently reported symptoms (as a percentage of occurrences over all four days) were throat irritation (33%), nasal irritation (30%), and eye irritation (28%). Aside from higher reporting of nasal symptoms during the last two survey days (conventional paving) and all the reports of throat irritation occurring during the first two days (CRM paving), there was no substantial difference in the types and numbers of symptoms reported by pavers between the paving periods. Seventy–six percent (35/46) of the symptoms reported by the pavers were rated as "mild" in severity (the choices were "mild," "moderate," or "severe").

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 conventional and CRM asphalt paving exposures. A more useful 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 and by period of exposure is presented in Table 16. The symptom reporting rate was about 95% higher during the CRM paving period (0.57 symptoms per completed questionnaire) as compared to the conventional paving period (0.29 symptoms per completed questionnaire).

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 17 shows each pavers' estimated exposure time to asphalt paving for each survey day. The average estimated hours of exposure to asphalt paving was slightly higher during the conventional paving period (7.0 hours of exposure/day), compared to the CRM paving period (6.3 hours of exposure/day). All eight of the non–pavers denied any exposure to asphalt paving throughout 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 18). The rate of symptom occurrences per hour of exposure was about 90% higher during the CRM paving period (0.40 symptom occurrences per hour of exposure) as compared to the conventional paving period (0.21 symptom occurrences per hour of exposure).

Pavers reported only four occurrences of lower airway symptoms (i.e., cough, shortness of breath, and wheezing) during the survey period. Additionally, the PEFR measurements did not reveal any workers with significant bronchial lability (i.e., difference between the minimum and the maximum PEFR on at least one day exceeded 20% of the day's maximum PEFR) on any survey day.

DISCUSSION

Weather

The ambient temperatures and wind conditions may affect air sampling measurements obtained outdoors during this (or any) construction project. The ambient temperatures on the two conventional asphalt paving sampling days (18 to 31°C [64 to 87°F]) were slightly warmer than the air temperatures estimated during the CRM asphalt paving period (≈17 to 21°C [≈63 to 70°F]). Based on the limited number of air samples collected during this site survey, it is uncertain what effect(s) the ambient temperatures may have had on asphalt fume generation.

While the ambient temperatures varied between the two types of asphalt paving, the wind direction, and to a lesser extent the wind speed, was more uniform. Throughout the four days of sampling, the wind was predominantly from the north at speeds ranging from 0 to 8 miles per hour (mph). The extent that these weather conditions influenced the air sampling results is uncertain, considering that the direction that the paving crew traveled differed between the two locations (CRM paving was approximately north to south (I–95 project), while the conventional paving was south to north (SR 138 project) and northeast to southwest (Elm Street).

Process Information

There were several potentially significant differences between the conventional and CRM asphalt paving construction projects during this survey, including the following:

- The production rate (number of tons of asphalt paved per hour) was about 1½ times higher during CRM asphalt paving than during conventional paving (190 tons/hour compared to 115 tons per/hour.)

- Two different HMA plants were used to supply the conventional and CRM asphalt.

- The HMA plants were different distances to their respective paving sites (a 20 minute commute for the CRM asphalt delivery trucks compared to a 45 minute commute for the conventional asphalt trucks).

- The CRM asphalt paving project was performed at night, while the conventional paving was conducted during the day.

- The CRM hot mix asphalt laydown temperature was approximately 14°C hotter than the conventional asphalt laydown temperature (177°C versus 163°C)

- Up to 10% recycled asphalt pavement (RAP) was used in the conventional asphalt mix.

- An AC–20 was used in the conventional asphalt mix, while an AC–10 was used in the CRM asphalt.

It is not known what impact some (or all) of these differences may have had on the environmental results obtained.

Air Sampling

The current NIOSH REL for asphalt fume is 5 mg/m^3 over a 15–minute exposure period, measured as TP. All of the PBZ sample concentrations were below this limit, although it is difficult to compare the full–shift sample results obtained in this evaluation to the 15–minute NIOSH REL. It is also important to realize that exposure limits are presently unavailable for several groups of compounds (such as total PACs, sulfur compounds, and benzothiazole) which were also present in the asphalt fume.

With the exception of benzene, concentrations of VOCs detected in area air samples located above the screed auger were well below any existing occupational exposure limits. During CRM asphalt paving benzene concentrations ranged from 0.051 to

0.77 ppm (concentrations during conventional asphalt paving were much lower). Although these sample results do not represent PBZ exposures, they do suggest that the potential exists for employee exposure to benzene, especially during CRM asphalt paving. NIOSH considers benzene to be an occupational carcinogen and recommends that exposure be reduced to the lowest feasible concentration.

Table 19 summarizes most of 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 Total particulate and benzene soluble particulate area concentrations were 5 to 6 times higher during CRM asphalt paving than during conventional paving.

P Total particulate PBZ concentrations were higher during CRM asphalt paving, although all full–shift PBZ exposures were well below the NIOSH short term REL of 5 mg/m^3 for asphalt fume exposure.

P As might be expected, the average TP PBZ concentrations measured on those jobs in closest proximity to fume emissions from either the paver or the asphalt delivery trucks were among the highest exposures, averaging 0.47 mg/m^3 on CRM asphalt paving days and 0.26 mg/m^3 on conventional asphalt paving days.

P Although TP PBZ concentrations were generally higher during CRM asphalt paving than during conventional asphalt paving, this difference is difficult to interpret due to the limited number of PBZ samples.

P The ratio of EC to TC suggests that diesel exhaust was not the primary contributor to the results of area and PBZ sampling for BSP, total PACs, and other sulfur–containing compounds.

P Two detector emission wavelengths were used to provide greater sensitivity either to 2–3 ring PACs (370 nm) or to 4+ ring PACs (400 nm). Regardless of the asphalt composition or whether the sample was a PBZ or area air sample, 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.

P Lower concentrations of sulfur–containing compounds (not including benzothiazole) were measured in area air samples collected during conventional asphalt paving (range 50 to 106 µg/m^3) than during CRM asphalt paving (range 112 to 233 µg/m^3). The average concentration of sulfur compounds over the screed auger during CRM asphalt paving was approximately twice as high as during conventional asphalt paving.

P Personal breathing–zone concentrations of other sulfur–containing compounds (not including benzothiazole) were slightly higher during CRM asphalt paving than during conventional paving.

P Benzothiazole was detected only during CRM asphalt paving. This was anticipated since benzothiazole is a sulfur–containing compound present in rubber tires. It also suggests that the crumb rubber in the CRM asphalt formulation is much more important than the rest of the components as a source of benzothiazole.

In addition to asphalt fume, two other potential occupational hazards worth noting (CO and noise) were identified during the road paving activities. Full–shift TWA concentrations of CO ranged from 8 to 24 ppm, below NIOSH and OSHA exposure limits. However, peak CO concentrations measured over one–minute sampling intervals ranged as high as 910 ppm (the NIOSH recommended ceiling limit for CO is 200 ppm). Although it is certainly possible that some peak CO concentrations may have resulted from exposure to cigarette smoke (since several of the pavers sampled smoked during the work shift), the presence of gasoline–powered generators on the paver vehicle and rollers (this equipment was used to provide power for lights during the CRM night paving) could also have contributed to the CO exposures. The noise exposures of 13 pavers were evaluated over the four days of this survey. All pavers' exposures exceeded the NIOSH REL for noise, and those of 11 of the 13 workers also exceeded OSHA action level for noise which requires the implementation of a hearing conservation program. NIOSH investigators observed that the majority of the paving crew on each paving day were not wearing any HPDs.

Medical

The results of the acute symptom survey revealed that among the pavers, the *rate of symptom occurrences per completed questionnaire* and the *rate of symptom occurrences per self–reported hour of asphalt paving* were approximately 90% higher 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 throat irritation during the CRM asphalt paving period.

Evaluation of acute symptoms in combination with peak flow testing was performed to determine whether acute respiratory symptoms were associated with intermittent or reversible bronchospastic responses. While 87% of the acute irritant symptoms were reported by workers in association with self–reported work site exposures, none of the pavers demonstrated significant bronchial lability on any of the survey days. The inability to detect an association, if truly present, between reported symptoms or exposures and PEFR 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 PEFR testing interval may not be of sufficient frequency to detect intermittently occurring transient bronchospastic effects.

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 PBZ exposures to asphalt fume emissions, as well as to other substances, were below current NIOSH RELs or other relevant exposure limits (for those substances that have them). The industrial hygiene data indicated some consistent differences in exposures between the conventional and CRM asphalt paving periods. For example, concentrations of TP, respirable particulate, BSF, PACs, and other sulfur–containing compounds (except benzothiazole) were higher in area samples collected during the CRM asphalt paving period. Also, PBZ concentrations of TP, BSF, total PACs, and other sulfur–containing compounds (except benzothiazole), while not as high as the area samples, were generally higher during the CRM asphalt paving period.

For pavers, the number of symptoms reported, the *rate of symptom occurrences per completed questionnaire*, and the *rate of symptom occurrences per self–reported hour of asphalt paving* were higher during the CRM asphalt paving period as compared to the conventional asphalt paving period. Although the higher symptom rates associated with CRM asphalt paving coincide 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. 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. A final composite report evaluating the findings of seven NIOSH site evaluations performed to date, is currently being prepared.

RECOMMENDATIONS

The following 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. A hearing conservation program should be instituted at Bardon–Trimount for the asphalt paving crews to reduce exposure to hazardous noise. At a minimum, the specifics of the program should meet the requirements stipulated in the OSHA noise regulation, including audiometric testing, employee notification, noise measurement, use of HPDs, employee training, and record keeping. The NIOSH technical report, "A practical guide to effective hearing conservation programs in the workplace," has been furnished to management and union personnel at the company to be used as a guide in implementing the program [Suter 1978].

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

3. 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.

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

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

6. The use of, and therefore exposure to, diesel fuel for the routine cleaning of equipment should be minimized.

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

8. Over the course of this survey workers performed 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
BSF	Benzene soluble (particulate) fraction
C	Ceiling, an exposure that shall not be exceeded during any part of the workday
°C	Degrees Celsius
CFR	Code of Federal Regulations
cm^2	Square centimeters
CO	Carbon monoxide
Control	A person working in road construction but not exposed to hot asphalt fume.
CRM	Crumb rubber modified
DOT	Department of Transportation
EC	Elemental carbon
EPA	Environmental Protection Agency
°F	Degrees Fahrenheit
FHWA	Federal Highway Administration
FID	Flame ionization detector
GC–MS	Gas chromatography–Mass Spectrometry
H_2S	Hydrogen sulfide
HHE	Health hazard evaluation
HMA	Hot mix asphalt
IARC	International Agency for Research on Cancer
ICP–AES	Inductively coupled (argon) plasma–atomic emission spectroscopy
IH	Industrial hygiene
ISTEA	Intermodal Surface Transportation Efficiency Act
LC	Liquid chromatography
LOD	Limit of detection (analytical method)
LOQ	Limit of quantitation (analytical method)
Lpm	Liters per minute
MCE	Mixed cellulose–ester filter
MDC	Minimum *detectable* 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.
mg	Milligrams
mg/m^3	Milligrams per cubic meter of air
MIBK	Methyl isobutyl ketone
mL	Milliliter
mm	Millimeter
MQC	Minimum *quantifiable* 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.
ND	Not detected

NIOSH	National Institute for Occupational Safety and Health
nm	Nanometer
OC	Organic carbon
OSHA	U.S. Occupational Safety and Health Administration
PAC$_{370}$	PACs monitored at an emission wavelength of 370 nanometers (representative of 2–ring and 3–ring compounds)
PAC$_{400}$	PACs monitored at an emission wavelength of 400 nanometers (representative of 4–ring and higher compounds)
PACs	Polycyclic aromatic compounds
PAHs	Polynuclear aromatic hydrocarbons
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$_2$	Sulfur dioxide
STEL	Short–term exposure limit
TC	Total carbon (elemental + organic)
TLV®	Threshold limit value (ACGIH exposure criteria)
TWA	Time–weighted average
VOCs	Volatile organic compounds
WBGT	Wet bulb globe temperature
°C & °F	Degrees Celsius and Degrees Fahrenheit
µg	Microgram (10^{-6}), a unit of weight
µg/m^3	Micrograms of contaminant per cubic meter of air (a unit of concentration)

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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) that is 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

TOTAL PARTICULATE AND BENZENE SOLUBLE FRACTION (ASPHALT FUME) 5042

CAS: 8052–42–4 asphalt; none, asphalt fume RTECS: CI990000, asphalt; none, asphalt fume

METHOD: 5042, Issue 1	**EVALUATION:**	**Issue 1**: 22 August 1997

OSHA: No PEL
NIOSH: 5 mg/m^3 ceiling (15–min) measured as total particulates
ACGIH: 5 mg/m^3

PROPERTIES: not defined

SYNONYMS: bitumen fumes

SAMPLING

SAMPLER:	FILTER (tared 37–mm, 2–µm PTFE filter)
FLOW RATE:	1 to 4 L/min
VOL-MIN:	28 L @ 5 mg/m^3
-MAX:	2400 L @ 0.8 mg/m^3
SHIPMENT:	Routine
SAMPLE STABILITY:	Not determined
BLANKS:	5 field blanks per day

ACCURACY

RANGE STUDIED:	Not determined
BIAS:	Not determined
OVERALL PRECISION ($\hat{S}_{rT}$):	Not determined
ACCURACY:	Not determined

MEASUREMENT

TECHNIQUE:	GRAVIMETRIC
ANALYTE:	Airborne total particulate (TP) material and benzene soluble fraction (BSF) of the airborne total particulate
EXTRACTION:	3 mL benzene; ultrasonic bath, 20 minutes
BALANCE:	0.001 mg sensitivity; use same balance if practical before and after sample collection
CALIBRATION:	Check and maintain calibration of balance according to manufacturer's recommendations
RANGE:	TP: 0.13 to 2 mg per sample BSF: 0.14 to 2 mg per sample
ESTIMATED LOD:	TP: 0.04 mg per sample BSF: 0.04 mg per sample
PRECISION ($\hat{S}_r$):	TP: 4.8% at ≥ 0.10 mg per sample BSF: 6.1% at ≥ 0.21 mg per sample

APPLICABILITY: The working range is 0.14 to 2 mg/m^3 for a 1000–L sample. The method is applicable to 15–minute samples. The method is evaluated for asphalt fume; however, the method is nonspecific and determines the concentrations of total particulates and the soluble fraction of the total particulates to which a worker is exposed. Therefore, for each sample matrix collected other than asphalt fume, a surrogate standard needs to be selected and spiked on sampling media. These spiked samples will be used to determine recoveries, precision, and accuracy, also LOD and LOQ if necessary; moreover, other solvents besides benzene can be evaluated. The particle size of the particulates should be less than 40 µm and preferably less than 30 µm. If particle sizes are larger than this, another sampler should be used.

INTERFERENCES: Changes in temperature or humidity during pre- and post-collection weighing may affect accuracy. A controlled laboratory environment is needed to exclude positive interferences due to dust contamination. Losses may occur due to air stripping or volatilization of a collected sample during sampling, shipping, or analysis.

OTHER METHODS: The total particulate portion of this method is based on NMAM 0500.

REAGENTS:

1. Benzene,* ≤ 5 ppm evaporation residue, e.g., Aldrich Chemical Co. Cat. No. 27,070–9 or equivalent.
2. Acetone,* HPLC grade.
3. Hexane,* HPLC grade.
4. Nitrogen,* purified and filtered.

* See SPECIAL PRECAUTIONS.

EQUIPMENT:

1. Sampler: 37–mm PTFE membrane filter laminated to PTFE (Zefluor, Gelman Sciences, Cat. No. P5PJ037; Supelco, Cat. No. 2–0043; SKC Cat. No. 225–17–07; or equivalent hydrophobic filter), 2-µm pore size, and cellulose support pad in a 37–mm cassette filter holder.
2. Personal sampling pump, 1 to 4 L/min, with flexible connecting tubing.
3. Balance, readable to 0.001 mg.
4. Static neutralizer: e.g., Po^{210}; replace according to manufacturer's recommendations.
5. Environmental chamber or room for balance (e.g., 20 °C ± 1 °C, constant ± 5% relative humidity, and dust–free).
6. Weighing cups,* PTFE, 2-mL (Fisher Cat. No. 2006529, or equivalent), in a carrying rack.
7. Vacuum oven, equipped with in-line filter on vacuum release valve to remove dust.
   NOTE: Keep the interior of the vacuum oven dust-free for maximum sensitivity, reproducibility, and accuracy.
8. Forceps.
9. Test tubes,** glass, 13–mm x 100–mm with PTFE-lined screw caps.
10. Pipet,** glass, volumetric 3–mL, with bulb.
11. Pipet,** glass, Mohr 2–mL, with bulb.
12. Clarification units, 1-µm PTFE frit with 6–mL PTFE treated reservoir (Daigger and Company, Inc. Cat. No. LID–2102–11US, or equivalent).
13. Pressure regulator, valve, tubing, in–line filter to remove dust and organics, and an adapter for applying nitrogen pressure to the clarification unit.
14. Ultrasonic bath.

* Rinse the weighing cups as follows.
  a. Wash with acetone until all visible residue is removed.
  b. Rinse with hexane for several seconds.
  c. Air–dry.
  d. Discard any weighing cups that are not visibly clean.

** Rinse all glassware with acetone then hexane; air–dry.

SPECIAL PRECAUTIONS: Benzene is a suspect carcinogen [1]. Asphalt fumes are considered a potential occupational carcinogen [1]. Benzene, hexane, and acetone are highly flammable. Prepare samples and standards in a well–ventilated hood and avoid skin contact. Use care when working with compressed gases.

PREPARATION OF FILTERS BEFORE SAMPLING:

1. Number the backup pads with a ballpoint pen and place them, numbered side down, in the filter cassette bottom sections.
2. Preweigh the filters by the procedure in step 3. Record the mean tare weight, W_1 or B_1 (µg).
3. Weighing procedure:
    a. Equilibrate the filters and weighing cups in an environmentally controlled weighing area or chamber for at least two hours.
    b. Zero the balance before each weighing.
    c. Using forceps, pass each filter or weighing cup over a static neutralizer. Repeat this step if the filter or weighing cup does not release easily from the forceps or attracts the balance pan. Static electricity can cause erroneous weight readings.
    d. Weigh each filter or weighing cup until a constant weight is obtained (two successive weighings within 10 µg). Record the mean of the last two weighings to the nearest microgram.
4. Assemble the filter in the filter cassette and close firmly to prevent leakage. Place a plug in each opening of the filter cassette. Place a cellulose shrink band around the filter cassette, allow to dry and mark with the same number as the backup pad.

SAMPLING:

5. Calibrate each personal sampling pump with a representative sampler in line.
6. Sample at an accurately known flow rate between 1 to 4 L/min for a total sample volume of 28 L to 2400 L. Do not exceed a total filter loading of approximately 2 mg total particulate.
7. Collect five field blanks for each day of field samples for determining the limit of detection (LOD) and the limit of quantitation (LOQ).

    Note: The LOD is equal to three times the standard deviation of the field blank weight differences (post–sampling weight – tare weight), and the LOQ is equal to ten times the standard deviation of the field blank weight differences. Field sample values should be compared to the LOD and LOQ values only after the field samples have been blank corrected.
8. Replace caps in cassette and ship to the laboratory. Recommend samples be refrigerated upon receipt at the laboratory.

CALIBRATION AND QUALITY CONTROL:

9. Use the same balance if practical for weighing filters and weighing cups before and after sample collection or benzene evaporation, respectively. Check and maintain calibration of balance according to manufacturer's recommendations. Zero the balance before each weighing.
10. Process three tared media blanks through the measurement procedures for total particulate and benzene soluble fraction.

MEASUREMENT FOR TOTAL PARTICULATE:

11. Wipe dust from the external surface of the filter cassette with a moist paper towel to minimize contamination. Discard the paper towel.
12. Remove the top and bottom plugs from the filter cassette. Equilibrate sampler for at least two hours in the balance room.
13. Remove the shrink band, pry open the cassette, and remove the filter gently to avoid loss of sample.
14. Reweigh each filter, including field blanks, as in step 3. Record the mean post–sampling weight, W_2 or B_2 (µg). Also, record anything remarkable about a filter (e.g., overload, leakage, wet, torn, etc.)
15. After weighing, transfer the filter carefully using forceps to a clean test tube and cap the tube.

CALCULATIONS FOR TOTAL PARTICULATE:

16. Calculate the concentration of total particulate, C_{TP} (mg/m^3), in the air volume sampled, V (L):

$$C_{TP} = \frac{(W_2 - W_1) - (B_2 - B_1)}{V}, \text{ mg/m}^3$$

where:
W_1 = mean tare weight of filter before sampling (µg)
W_2 = mean post–sampling weight of sample–containing filter (µg)
B_1 = mean tare weight of field blank filters (µg)
B_2 = mean post–sampling weight of field blank filters (µg)

MEASUREMENT FOR BENZENE SOLUBLE FRACTION:

17. Condition clarification unit by rinsing the reservoir with 1.5 mL of benzene. Use nitrogen pressure to force the benzene through the frit. Appropriately dispose of the benzene rinse.
18. Add 3.0 mL benzene via a 3–mL volumetric pipet to the test tube saved in step 15. Recap the test tube.
19. Place the test tube upright in beaker containing water to the same level as the liquid in the test tube. Place the beaker and test tube in ultrasonic bath and sonicate for 20 minutes.
20. Transfer benzene extract to conditioned clarification unit and filter into a clean test tube, using nitrogen pressure as in step 17. Discard sampling filter and clarification unit.
    Note: Be sure the end of the clarification unit is well below the opening of the test tube to prevent sample loss by spattering.
21. Prerinse weighing cup as described in the Equipment section.
22. Preweigh a clean weighing cup by the procedure in step 3. Record the mean tare weight, W_3 or B_3 (µg).
23. Identify each tared weighing cup by labeling its place in the carrying rack.
24. Transfer a 1.5–mL aliquot of the benzene extract via a 2–mL Mohr pipet to the tared weighing cup.
    NOTE: An aliquot may be taken from the remaining extract at this step if other analyses (e.g., polycyclic aromatic compounds) are to be performed on the sample. Apply the appropriate aliquot factor in calculations.
25. Place the weighing cup rack in a vacuum oven preheated to 40 °C. Apply vacuum until pressure in the oven is 7 to 27 kPa (50 to 200 mm Hg). Allow solvent to evaporate (about two hours). Release the vacuum by slowly opening a release valve that has an in–line filter to remove room dust.
26. Reweigh the weighing cup, as in step 3. Record the mean post–sampling weight, W_4 or B_4 (µg). Also, record anything remarkable about the sample (e.g., overload, leakage, wet, spattering, etc.).
27. After weighing the weighing cup, clean the weighing cup as described in the Equipment section.

CALCULATIONS FOR BENZENE SOLUBLE FRACTION:

28. Calculate the concentration of benzene solubles fraction, C_{BSF} (mg/m^3), in the air volume sampled, V (L):

$$C_{BSF} = \frac{[(W_4 - W_3) - (B_4 - B_3)] \cdot 2}{V}, \text{ mg/m}^3$$

where: W_3 = mean tare weight of sample weighing cup (µg)
W_4 = mean post–sampling weight of sample weighing cup (µg)
B_3 = mean tare weight field blank weighing cups (µg)
B_4 = mean post–sampling weight of field blank weighing cups (µg)
The 2 is needed as an aliquot factor

EVALUATION OF METHOD:

Asphalt fume collected during a previous NIOSH investigation [2] was spiked on tared PTFE filters, allowed to dry at least overnight, and extracted using benzene. The results are summarized in the table below.

	Total Particulates		**Benzene Soluble Fraction**	
Spiking level (mg)*	**Recovery (%)**	**SD (%)**	**Recovery (%)**	**SD (%)**
1.85	102	6.1	97.9	0.7
1.17	103	4.1	98.2	2.0
0.62	94.0	5.5	94.8	1.7
0.23	91.6	3.2	96.9	5.9
0.12	82.1	3.2	80.9	7.7
0.058	110	18.0	92.1	12.5
0.025	105	12.0	73.1	12.7

*Six replicates per level

The pooled precision for the total particulates was 4.8% at or greater than 0.10 mg per sample of total particulate collected. For the benzene soluble fraction, the pooled precision was 6.1% at or greater than 0.20 mg per sample of total particulate collected.

The accuracy criterion is based on determining the range of analyte loadings and analyte loading on the sample media that will give at least an upper 95% confidence limit of obtaining a measurement of the analyte that is within 25% of the true value 95% of the time. Since no independent method for determining the total particulate concentration is available, no estimate of the bias for the total particulate data was made; therefore, the maximum allowable bias was calculated at which the accuracy criterion could still be met. Based on the spiking data, if the total particulate loading was equal to or greater than 0.10 mg per filter, the measurement determination will be within 25% of the true value 95% of the time if the true bias is less than 11.5%. The bias for the benzene soluble fraction was negative (see the data above), and since the bias for the benzene soluble fraction varied little, the bias was pooled over the spiking range of 1.85 to 0.20 mg per filter. It was determined that the 25% accuracy criterion was met if the total particulate loading for the benzene soluble fraction was equal to or greater than 0.20 mg per filter.

The limit of detection (LOD) and the limit of quantitation (LOQ) were determined using field blanks.[3] The standard deviations of the field blank weights were 0.013 mg per sample for total particulates and 0.014 mg per sample for the benzene soluble fraction. Therefore, the LOD and LOQ for total particulates were 0.04 and 0.13 mg per sample, respectively. The LOD and LOQ for the benzene soluble fraction were 0.04 and 0.14 mg per sample, respectively. These LOD and LOQ values should only be compared to blank corrected field sample data.

A user check of the method was performed, in which tared PTFE filters were spiked with 1.08, 0.392, or 0.216 mg of pyrene per filter and then analyzed by an independent chemist.[3] A mean total particulate recovery of 106% (SD = 6.1%) was obtained, and benzene soluble fraction recovery was 109% (SD = 11.0%). Correlation of benzene soluble mass with total particulate was linear, with $R^2 = 0.994$, and the mean ratio of benzene soluble mass to total particulate was 106% (SD = 8.2%).

In other experiments, three of 60 field blanks had a significantly higher than expected benzene soluble fraction when compared with the other field blanks.[3] This event had two undesirable consequences: 1. Because the average weight of the field blanks was increased, the field samples were over corrected, and 2. The standard deviation of the field blank weights was increased, in one case by a factor of 1.6, resulting in higher LOD and LOQ values. Since this event may occur with field samples, these elevated results were not excluded when the data were evaluated. Although these events were observed with a syringe type clarification unit and not the recommended clarification unit, the cause of this event was not determined. Therefore, it is important to collect as many field blanks as is reasonable (five blanks per day); also, it may be advisable to establish a monitoring program to track the occurrence of elevated field blanks and, if possible, to identify and eliminate the cause(s).

In another experiment, the recommended clarification unit (PTFE treated reservoir and a PTFE filter) was evaluated along with three syringe type clarification units.[3] The recommended clarification unit gave lower average extractable material than the three syringe type clarification units; also, the recommended clarification unit did not release increasing amounts of extractable material upon prolonged contract with solvent. Prerinsing the recommended clarification unit appeared to lower the average amount of extractable material. Additionally, the recommended clarification unit eliminated the need for using a glass syringe and was more convenient to use than the three syringe type clarification units.

In a preliminary asphalt fume spiking experiment, benzene and methylene chloride were evaluated as extraction solvents.[3] Asphalt fume [2] was spiked on tared PTFE filter media at the following concentrations: 3.38, 0.68, 0.14, and 0.034 mg per filter. Benzene gave recoveries greater than 100% for all concentrations of asphalt fume spiked on PTFE filters. While methylene chloride gave recoveries greater than 100% for the two highest levels spiked, at the two lower levels the recoveries were less than or equal to 66%.

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APPENDIX C

ELEMENTAL CARBON (DIESEL EXHAUST) 5040

CMW: 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

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SAMPLING

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^3
–MAX: 4300 L (for filter load ~ 20 µg/cm^2)

SHIPMENT: routine

SAMPLE STABILITY: stable

BLANKS: 2 to 10 field blanks per set

ACCURACY

RANGE STUDIED: 4.0 mg/m^3
(60–L sample) [1]

BIAS: none [1]

OVERALL PRECISION ($\hat{S}_{rT}$): see EVALUATION OF METHOD

ACCURACY: see EVALUATION OF METHOD

MEASUREMENT

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

ANALYTE: elemental carbon (EC)

FILTER PUNCH SIZE: 1.54 cm^2

CALIBRATION: methane injection [1]

RANGE: 0.76 to 54 µg per filter portion

ESTIMATED LOD: 0.2 µg per filter portion

PRECISION ($\hat{S}_r$): 0.10 @ 1 µg C,
0.01 @ 10 – 72 µg C

APPLICABILITY: The working range is 4.4 to 312 µg/m^3 with an LOD of ~1.3 µg/m^3 for a 960–L air sample collected on a 37–mm filter with a 1.54 cm^2 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^3) [1]. The split between organic–based carbon (OC) and EC may be affected at higher EC loadings (e.g., >30 µg/cm^2 of filter), depending on type and amount of OC present. If pyrolysis correction is not required, an upper limit of ~800 µg/m^3 (90 µg/cm^2) 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^2 with diameter or width of $\leq$ 1 cm is recommended.
5. Syringe, 10–µL

SPECIAL PRECAUTIONS: None

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_4 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_2O 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, µg, as provided by analyzer and divide by sample punch area, cm^2, to report result in terms of µg C per cm^2 of filter.

CALCULATIONS:

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

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

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 (± 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., ≈ 0.24 µg C or 0.15 µg C/cm^2), ethylenediaminetetraacetic acid (EDTA) calibration standards covering a range from 0.23 to 2.82 µg C (or from 0.15 to 1.83 µg C per cm^2 of filter) were analyzed. Results of linear regression of the low–level calibration data (i.e., µg C reported vs. actual) were then used to calculate the LOD as $3\,\sigma_y/\mathbf{m}$ (where σ_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 LOD = (blank + $3\sigma_{blank}$), which gives a value of ≈ 0.22 µg C. The mean (n = 40) instrumental blank was ≈ .02 (± 0.07) µg 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 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 µg per sample) would be equivalent to sampling an EC level of 250 µg/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–µm cutpoint is required to minimize the contribution of coal–source EC [2].

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METHOD WRITTEN BY:

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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^3 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 $\mu g/cm^2$ 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 CO_2 in a bed of granular MnO_2 (at 950°C), CO_2 is reduced to CH_4 in a Ni/firebrick methanator (at 450°C), and CH_4 is quantified by an FID. In the second stage of the analysis, the oven temperature is reduced, an oxygen–helium mix (2% 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 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.

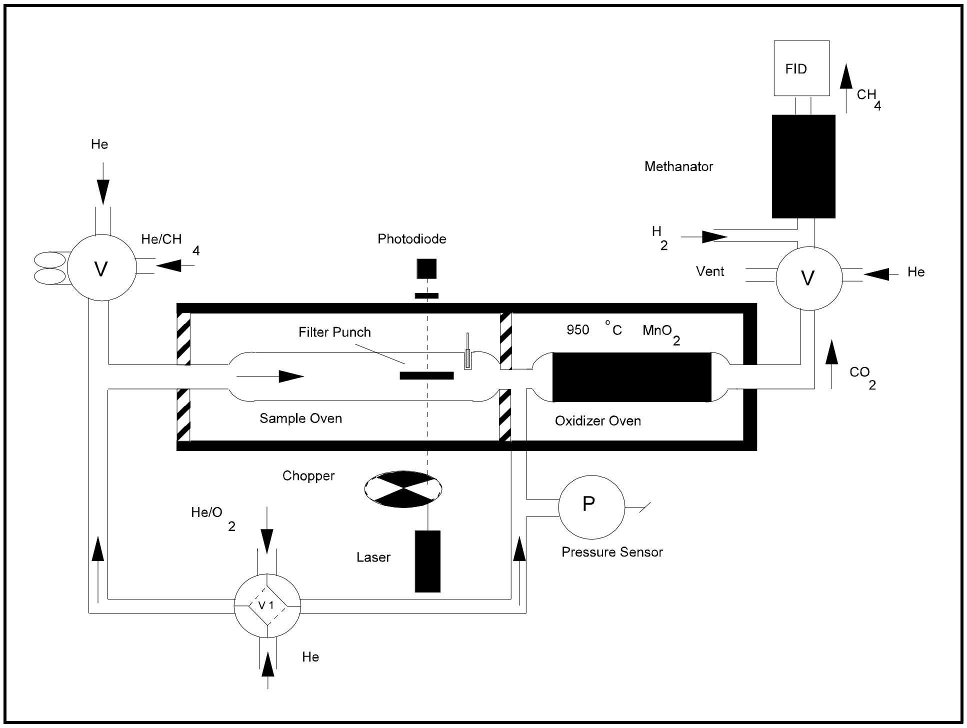

Figure 1. Schematic of Thermal–Optical Analyzer.

Table 1
Production and Equipment Information
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

National Institute for Occupational Safety and Health

NIOSH • **Delivering on the Nation's promise: Safety and health at work for all people through research and prevention**

Description	7/22/97 Conventional	7/23/97 Conventional	6/25/97 CRM	6/27/97 CRM
Pavement Function	Surface friction course for Rt. 138, a 2-lane rural road (width ~ 30 to 34 ft.)	Surface friction course for two different 2-lane rural roads (Rt. 138 & Elm St.). The road widths ranged from ~ 20 to 34 ft.	Dense binder course for section of I-95 12' right lane and 10' shoulder	Dense binder course for section of I-95 three lanes @ 12 ft./lane, plus 10 ft. breakdown lane
Hot Mix Asphalt Type	Modified top mix (60% screenings/40% sand); Aggregate ≤ 3/4"	Modified top mix (60% screenings/40% sand); Max. aggregate size 1/2"	CRM asphalt 19 millimeter (3/4') maximum grade	CRM asphalt 19 millimeter (3/4') maximum grade
Crude Supplier	Bardon-Trimount, Newington, NH	Bardon-Trimount, Newington, NH	Bardon-Trimount, Newington, NH	Bardon-Trimount, Newington, NH
Asphalt Cement Grade	AC-20	AC-20	AC-10	AC-10
% Binder Content	5.6%	6.2%	6.6%	6.6%
Asphalt Cement Temp. at Storage Tank	≈163°C (325°F)	≈163°C (325°F)	≈177°C (350°F)	≈177°C (350°F)
% Rubber (total weight of rubber by total weight of asphalt/rubber blend)	NA	NA	16% (Supplier: NRB Materials, Inc., Chambersburg, PA)†	16% (Supplier: NRB Materials, Inc., Chambersburg, PA)
Rubber Blending	NA	NA	Wet Method	Wet Method
Production, in metric tons	904 (997 short tons)	1027‡ (1132 short tons)	1,089 (1,200 short tons)	1,451 (1,600 short tons)
Laydown Temperature, Asphalt (uncompacted)	141°C (285°F)	141°C (285°F)	154°C (310°F)	152°C (305°F)
Mat Thickness (uncompacted)	≈6.4 centimeters	≈6.4 centimeters	≈5.7 to 6.4 centimeters	≈5.7 to 6.4 centimeters
Laydown Width	Crew was paving a two lane rural road, ranging in width from 9.9 to 10.4 meters (30 to 34 feet)	Work continued from previous day, paving 9.9 to 10.4 meters (30 to 34 feet). Crew then switched to a paving a more narrow 6.1 meter road (≈20 ft.)	Right Lane: 3.7 meters (12 ft.) Shoulder: 3 meters (10 ft.)	H.S. Lane & Shoulder: 4.9 meters (16 ft.) Middle Lane: 3.7 meters (12 ft.) Right Lane: 3.7 meters (12 ft.)
Hot Mix Asphalt Conveyance	Tri-axle dump trucks (capacity ranged from approx. 22 to 31 metric tons)	Tri-axle dump trucks (capacity ranged from approx. 22 to 31 metric tons)	Tri-axle dump trucks (average capacity approx. 22 metric tons)	Tri-axle dump trucks (average capacity approx. 22 metric tons)
Job Duration (approximation)	8.25 hours	8.5 hours	5.5 hours	8 hours
Windrower Pick–up	No	No	No	No
Paver	Barber Greene (model unknown)	Barber Greene (model unknown)	Barber Greene, Model BG 245C	Barber Greene, Model BG 245C
Roller (breakdown)	Yes	Yes	Yes	Yes
Roller (intermediate)	No	No	Yes	Yes
Roller (finishing)	Yes	Yes	Yes	Yes
Average Production Rate	110 metric tons/hour	120 metric tons/hour	198 metric tons/hour	181 metric tons/hour

† Rubber blending subcontractor: All-State Asphalt, Inc., Amhurst Road, Route 116, Sunderland, MA 01375

‡ The total shown here (1027 metric tons) combines the 675 metric tons paved on Rt. 138 = 744 between ≈ 7:10 am to 1:00 pm with the 352 metric tons paved on Elm St. from ≈ 1:30 pm to 4:45.

Table 2
Summary of Sampling and Analytical Methods
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Substance	Flow Rate (Lpm)	Sample Media	Analytical Method	Comments
Total Particulate‡	2.0	Tared Zefluor filter (37 mm diameter, 1 µm pore size)	NIOSH Method No. 0500, with modifications Gravimetric analysis	The modification to this method involved substituting a tared Zefluor filter in place of a tared PVC filter for sample collection. Both personal breathing-zone and area samples collected
Respirable Particulate	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
Polycyclic Aromatic Compounds (PACs) and Sulfur Compounds	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.
Benzene Soluble‡ Particulate	2.0	Tared Zefluor filter (37 mm diameter, 1 µm pore size) Note: In three of the six NIOSH asphalt paving surveys conducted prior to this evaluation, a glass fiber filter was used.	Draft NIOSH Method 5042. The filters were rinsed with benzene, the leachate collected and evaporated, and the residue weighed to report the benzene soluble fraction. 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. A copy of the draft NIOSH Method 5040 is provided as Appendix B.
Elemental/Organic Carbon	2.0	Quartz-fiber filters (37 mm diameter, open face)	A rectangular punch (1.54 cm^2) is taken from the quartz filter for a three stage thermal-optical analysis.	A copy of NIOSH Method 5040 is provided as Appendix C.
Qualitative Volatile Organic Compound (VOC) Screen	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.
Quantitative Analysis for Selected Solvents	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.	SpecificVOCs that were quantified included benzene, toluene, xylene, MIBK, and petroleum distillates (other hydrocarbons with retention times either less than or greater than toluene).

Table 2
Summary of Sampling and Analytical Methods
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Substance	Flow Rate (Lpm)	Sample Media	Analytical Method	Comments
H_2S, SO_2, CO, and Ozone	Diffusion	Toxilog® diffusion monitors for H_2S, SO_2, CO. CEA® TG-KA Portable Toxic Gas Detector for ozone	Toxilog® diffusion monitors use individual electrochemical sensors specific for H_2S, SO_2, 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.
Mutagenic Potential	≈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. [Houk et al. 1991; Mut. Res. 1989].	Area samples were collectedin 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.

‡ **Draft NIOSH Sampling and Analytical Method No. 5042 was used to measure both total particulate and the benzene soluble particulate fraction from the same sample filter. The advantage to this approach is that additional personal breathing-zone information may be obtained. The most significant modification involved using a 37 millimeter, 1.0 µm pore size tared Zefluor filter in place of a tared PVC filter typically used for total particulate sampling. A copy of this draft method, used previously in HETA 95-0307-2602, HETA 96-0072-2603, and HETA 96-0130-2619, has been included in Appendix B of this report.**

The following are abbreviations which were not spelled out in the table.

PVC = Polyvinyl chloride sampling filter
mm = millimeter
µm = micrometer
GC-FID = Gas chromatography-flame ionization detector
H_2S = Hydrogen sulfide
HPLC = High pressure liquid chromatography
SO_2 = Sulfur dioxide
CO = Carbon monoxide
lpm = Liters per minute
MIBK = Methyl isobutyl ketone
Zefluor = Teflon® sampling filter
nm = Nanometer

Table 3
Toxicity and Exposure Criteria Information
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Compound	Toxicity Review	Exposure Criteria
Asphalt Fume **(As Total Particulate)**	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.	The NIOSH REL is 5 mg/m^3 for a 15-minute ceiling exposure. There is no current OSHA PEL for asphalt fume. The ACGIH TLV® is 5 mg/m^3 as an 8-hour TWA to total particulate.
Respirable Particulate	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. 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.	No NIOSH REL The OSHA PEL is 5 mg/m^3, 8-hour TWA. The ACGIH TLV® for particulates not otherwise classified is 10 mg/m^3 for inhalable particulate and 3 mg/m^3 for respirable particulate. Both are 8-hour TWAs.
Benzene Soluble Particulate	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. 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).	None established for BSF associated with asphalt fume
Polynuclear Aromatic Hydrocarbons **and** **Polycyclic Aromatic Compounds**	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. 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. NIOSH investigators have hypothesized that PACs with 2 to 3 rings (referred to in this report as PAC$_{370}$) are associated with more irritative effects, while the 4 to 7 ring PACs (termed PAC$_{400}$) may have more carcinogenic and/or mutagenic effects. It is not currently posssible 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.	None established for PAHs and PACs as a class.

Table 3
Toxicity and Exposure Criteria Information
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Compound	Toxicity Review	Exposure Criteria
Benzothiazole	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
Other Sulfur-Containing Compounds	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
Organic and Elemental Carbon	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
MIBK	Tire rubber may be a source for methyl isobutyl ketone (MIBK) since this organic compound can be used as an antioxident 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.
Benzene	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.
Toluene	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 [Hathaway 1991, 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
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Compound	Toxicity Review	Exposure Criteria
Xylene	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].	NIOSH REL is 100 ppm, 8-hour TWA. OSHA PEL is 100 ppm, 8-hour TWA. ACGIH TLV is 100 ppm for an 8-hour TWA and 150 ppm for a 15-minute STEL
Total Hydrocarbons **(as either n-hexane or Stoddard solvent)**	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 [Hathaway 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).	NIOSH REL is 350 mg/m^3, 10-hour TWA (for all petroleum distillate mixtures, including Stoddard solvent). The NIOSH ceiling limit is 1800 mg/m^3, 15 minutes. OSHA PEL for Stoddard solvent is 2,900 mg/m^3, 8-hour TWA. ACGIH TLV for Stoddard solvent is 525 mg/m^3, 8-hour TWA.
		NIOSH REL for n-hexane is 180 mg/m^3 for up to a 10-hour TWA. OSHA PEL for n-hexane is 1,800 mg/m^3, 8-hour TWA. ACGIH TLV for n-hexane is 176 mg/m^3, 8-hour TWA.

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^3 = milligrams per cubic meter

Table 4
Summary of Environmental Conditions
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Description	**7/22/97 Conventional Asphalt**	**7/23/97 Conventional Asphalt**	**6/25/97 CRM Asphalt**	**6/27/97 CRM Asphalt**
Summary	Paving initially delayed until 9:00 am due to a light rain. It was sunny for the remainder of the day with a slight breeze from the northwest and northeast.	Entire day was sunny with a slight but steady breeze from the northeast.	Because of a lack of instrumentation, no weather information was collected during the two evenings of CRM asphalt paving on June 25 and 27, 1997. A subjective weather evaluation of these evenings are mild winds (predominately from the north), with temperatures in the low- 70's.	
Minimum Temperature	22°C (72°F)	18°C (65°F)	Not collected	Not collected
Maximum Temperature	31°C (87°F)	26°C (79°F)	Not collected	Not collected
Humidity (Range)	29 to 76%	42 to 76%	Not collected	Not collected
Minimum WBGT_{OUT}	72.8°F	65.4°F	Not collected	Not collected
Maximum WBGT_{OUT}	82.5°F	72°F	Not collected	Not collected
Wind Speed	0 to 7 mph	3 to 8 mph	Not collected	Not collected
Wind Direction †	Winds predominately from the northwest and northeast	Winds predominately from the northeast	Winds predominately from the north	Winds predominately from the north
Estimated Traffic Density	Low	Low	Heavy	Heavy

WBGT = Wet bulb globe temperature, a heat stress index
Conventional = Hot mix asphalt which does not contain curmb rubber
CRM = Crumb rubber modified hot mix asphalt

† The Transportable Automated Meteorological Station (TAMS) did not arrive in time to collect wind direction and speed information on June 25 and 27, 1997.

Table 5
Total Particulate and Benzene Soluble Particulate Concentrations: Area Samples
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Sampling Date	Area	Sampling Time (minutes)	Sample Volume (Liters)	Concentration (mg/m^3)	
				Total Particulate	Benzene Soluble Particulate
Conventional Asphalt Paving **7/22/97**	Screed Left (a)‡	512	1024	1.4	1.2
	Screed Left (b)	513	1026	1.4	1.2
	Screed Right (a)	508	1016	1.4	1.2
	Screed Right (b)	509	1018	1.5	1.2
	Highway Background (1)	382	714	0.013	ND (<0.008)
	Highway Background (2)	409	818	0.037	ND (<0.008)
	Highway Background (3)	406	812	0.037	ND (<0.008)
Conventional Asphalt Paving **7/23/97**	Screed Left (a)	590	1180	1.5	1.3
	Screed Left (b)	590	1180	1.6	1.4
	Screed Right (a)	582	1135	1.8	1.6
	Screed Right (b)	450†	900	1.9	1.6
	Highway Background (1)	526	1052	0.019	ND (<0.006)
	Highway Background (2)	553	1106	0.036	ND (<0.005)
	Highway Background (3)	562	1152	0.034	0.026
CRM Asphalt Paving **6/25/97**	Screed Left (a)	330	660	6.0	5.8
	Screed Left (b)	330	660	6.5	6.4
	Screed Right (a)	328	640	8.8	8.5
	Screed Right (b)	328	656	8.1	7.7
	Highway Background (1)	329	658	0.073	ND (<0.009)
	Highway Background (2)	269	538	0.061	ND (<0.011)
	Highway Background (3)	261	522	0.088	ND (<0.011)
CRM Asphalt Paving **6/27/97**	Screed Left (a)•	343	686	11	9.8
	Screed Left (b)•	299	598	12	10
	Screed Right (a)•	342	684	8.4	7.5
	Screed Right (b)•	290	580	8.7	8.1
	Highway Background (1)	460	920	0.066	0.043
	Highway Background (2)	437	874	0.023	ND (<0.007)
	Highway Background (3)	434	868	0.009	ND (<0.007)

ND = Not Detected (below the Minimum Detectable Concentration).
mg/m^3 = Concentration, milligrams per cubic meter
( ) = 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.
‡ = A total of four area samples were collected daily at the screed (two on either side). These samples are referred to as (a) and (b).
† = The first sampling pump faulted during the sampling period and was replaced with a new pump. The sample media was not changed.
• = The first sampling pump faulted but was not replaced (shown is the time the pump operated before faulting). The sample media was not changed.

Table 6
Respirable Particulate Concentrations: Area Samples
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Sampling Date	Area	Sampling Time (minutes)	Sample Volume (Liters)	Concentration (mg/m^3)
Conventional Asphalt 7/22/97	Screed Left	512	845	0.44
	Screed Right	475	808	0.59
	Highway Background	382	649	0.88#
Conventional Asphalt 7/23/97	Screed Left	590	1003	0.58
	Screed Right	585	995	0.77
	Highway Background	526	894	0.11
CRM Asphalt Paving 6/25/97	Screed Left	330	561	2.5
	Screed Right	192†	326	4.8
	Highway Background	329	559	0.072
CRM Asphalt Paving 6/27/97	Screed Left	271‡	461	4.6
	Screed Right	342‡	581	3.0
	Highway Background	451	767	ND (<0.03)

Comments and Abbreviations:

ND = Not Detected (below the Minimum Detectable Concentration, shown in brackets)
mg/m^3 = Concentration, milligrams per cubic meter
† = The initial sampling pump faulted and was replaced with a new pump. The sampling media was not replaced.
‡ = The first sampling pump faulted but was not replaced (shown is the time the pump operated before faulting). The sample media was not changed.
# = This background sample is considered suspect since the respirable particulate concentration is 8 to 12 times higher than the other background concentrations for respirable particulate collected in this study.

Table 7
Concentrations of Polycyclic Aromatic Compounds (PACs): Area Samples
Paving Site:Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Sampling Date	Area	Sampling Time (minutes)	Sample Volume (Liters)	Concentration, micrograms per cubic meter			
				PACs @ 370 nm	PACs @ 400 nm	Other SulCom	Benzothiazole
Conventional Asphalt Paving **7/22/97**	Screed Left (a)‡	512	1024	429	72	95	ND (<0.06)
	Screed Left (b)	513	1077	440	81	50	ND (<0.06)
	Screed Right (a)	508†	No data is available since the filter cassette was damaged during sampling.				
	Screed Right (b)	508	1041	466	97	70	ND (<0.06)
	Highway Background	382	745	2.7	0.32	ND (<0.08)	ND (<0.08)
Conventional Asphalt Paving **7/23/97**	Screed Left (a)	590	1121	393	77	78	ND (<0.05)
	Screed Left (b)	590	1151	450	83	103	ND (<0.05)
	Screed Right (a)	582	1135	281	60	106	ND (<0.05)
	Screed Right (b)	588	1147	486	88	104	ND (<0.05)
	Highway Background	526	1026	ND (<0.06)	ND (<0.06)	ND (<0.06)	ND (<0.06)
CRM Asphalt Paving **6/25/97**	Screed Left (a)	330	660	2029	130	112	88
	Screed Left (b)	330	660	2062	145	133	100
	Screed Right (a)	328	656	2832	279	264	81
	Screed Right (b)	328	656	2666	273	233	233
	Highway Background	329	658	10	ND (<0.09)	ND (<0.09)	ND (<0.09)
CRM Asphalt Paving **6/27/97**	Screed Left (a)	441	882	2601	192	207	90
	Screed Left (b)	440	858	1853	203	295	104
	Screed Right (a)	467	911	2027	181	165	157
	Screed Right (b)	444	888	2257	177	232	179
	Highway Background	459	918	7.0	ND (<0.07)	ND (<0.07)	ND (<0.07)

† = The plastic filter cassette was damaged during sampling and the air flow was disrupted. A total air sample volume could not accurately be determined.
PACs = Polycyclic Aromatic Compounds
SulCom = Other sulfur-containing compounds
370 nm = 370 nanometers, spectrofluorometric detector wavelength (includes both vapor and particulate phase)
400 nm = 400 nanometers, spectrofluorometric detector wavelength (includes both vapor and particulate phase)
ND = Not Detected (below the Minimum Detectable Concentration)
‡ = A total of four area samples were collected daily at the screed (two on either side). These samples are referred to as (a) and (b).

Other Comments:
Air samples were collected using 37 millimeter Zefluor® filters followed by an ORBO 42 sorbent tube.

Table 8
Elemental Carbon Concentrations: Area Samples
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Sampling Date	Area	Sampling Time (minutes)	Sample Volume (Liters)	Concentration, micrograms per cubic meter			EC:TC
				Organic Carbon (OC)	Elemental Carbon (EC)	Total Carbon (TC)	
Conventional Asphalt **7/22/97**	Screed Left	514	1028	982	11	992	1.1%
	Screed Right	509	1018	1159	14	1173	1.2%
	Highway Background	382	745	ND (<2.3)	ND (<5.8)	ND (<5.8)	N/A
Conventional Asphalt **7/23/97**	Screed Left	588	1176	1149	8.5	1157	0.7%
	Screed Right	580	1189	1280	10	1290	0.8%
	Highway Background	526	1052	ND (<1.6)	Trace (2.0)	Trace (2.0)	N/A
CRM Asphalt Paving **6/25/97**	Screed Left	330	660	3252	62	3314	1.9%
	Screed Right	328	656	6399	46	6445	0.7%
	Highway Background	329	674	65	ND (<3.9)	65	N/A
CRM Asphalt Paving **6/27/97**	Screed Left	433	844	7198	132	7739	1.7%
	Screed Right	446	892	3556	115	3672	3.1%
	Highway Background	461	922	35	ND (<2.8)	35	N/A

Abbreviations:

EC:TC = Ratio of Elemental Carbon to Total Carbon
N/A = Not applicable since one or both analytes were not detected or present in trace amounts.

Comments:

1. Results have been rounded off to the nearest whole number.
2. Since the analytical results reported organic and elemental carbon were reported in micrograms per centimeter, a correction factor of 8.55 was used to calculate the weights for the entire filter surface area.

Table 9
Concentrations of Selected Volatile Organic Compounds (VOCs): Area Samples
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Sampling Date	Area	Sampling Time (minutes)	Sample Volume (Liters)	Concentration, expressed in parts per million				Concentration, expressed in mg/m^3	
				Benzene	**Toluene**	**Xylene**	**MIBK**	**Total HC< Toluene†**	**Total HC > Toluene‡**
Conventional Asphalt Paving 7/22/97	Screed (left)	513	103	Trace	0.014	0.055	0.018	1.3	15
	Screed (right)	506	101	0.011	0.024	0.092	0.031	2.0	23
Conventional Asphalt Paving 7/23/97	Screed (left)	567•	113	0.011	0.035	0.10	0.038	2.3	24
	Screed (right)	578	116	0.011	0.036	0.11	0.039	2.3	24
CRM Asphalt Paving 6/25/97	Screed (left)	330	66	0.051	0.051	0.32	0.44	4.8	71
	Screed (right)	334	67	0.17	0.16	1.0	1.4	16	224
CRM Asphat Paving 6/27/97	Screed (left)	339	68	0.11	0.11	0.60	1.1	9.9	126
	Screed (right)	442	88	0.77	0.78	0.44	0.68	6.0	86
Minimum Detectable Concentration		100 Liter air sample volume		0.0031	0.0026	0.0027	0.0024	0.01	0.2
Minimum Quantifiable Concentration		100 Liter air sample volume		0.010	0.0086	0.0075	0.0079	0.033	0.8

mg/m^3 = Concentration, expressed in milligrams per cubic meter.
MIBK = Methyl isobutyl ketone.
Trace = Concentration is between the Minimum Detectable and Minimum Quantifiable Concentrations.
† = Total hydrocarbons with a gas chromatograph retention time less than (<) toluene. Expressed in milligrams per cubic meter (mg/m^3) and quantified as n-hexane.
‡ = Total hydrocarbons with a gas chromatograph retention time greater than (>) toluene. Expressed in milligrams per cubic meter (mg/m^3) and quantified as Stoddard Solvent.
• = The first sampling pump used faulted and was replaced.

Table 10
Total Particulate and Benzene Soluble Particulate Concentrations: Personal Breathing-Zone Samples
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Sampling Date	Activity	Sampling Time (minutes)	Sample Volume (Liters)	Concentration (mg/m^3)	
				Total Particulate	Benzene Soluble Particulate
Conventional Asphalt Paving **7/22/97**	Paver Operator (Left Side)†	504	983	0.23	0.15
	Paver Operator (Right Side)†	488	976	0.37	0.24
	Screed Operator•	505	1010	0.27	0.099
	Raker/Laborer	438	876	0.16	0.080
	Raker/Laborer	501	952	0.15	0.042
	Roller Operator (Breakdown)	446	892	0.10	0.045
	Roller Operator (Finish)✓	433	866	0.058	0.037
Conventional Asphalt Paving **7/23/97**	Paver Operator (Left Side)†	576	1152	0.30	0.15
	Paver Operator (Right Side)†	576	1152	0.52	0.40
	Screed Operator•	585	1170	0.18	0.068
	Raker/Laborer	553	1106	0.19	0.054
	Raker/Laborer	570	1140	0.18	0.052
	Roller Operator (Breakdown)	553	1170	0.034	0.027
	Roller Operator (Finish)✓	532	1064	0.047	0.019
CRM Asphalt Paving **6/25/97**	Paver Operator (Left Side)	325	650	0.42	0.24
	Screed Operator•	330	660	0.31	0.12
	Raker/Laborer	330	660	0.17	0.094
	Raker/Laborer	327	670	0.34	0.10
	Mechanic✓	328	656	0.57	0.24
	Traffic Control✓	333	666	0.58	0.063
	Roller Operator (Breakdown)	333	666	0.11	0.039
CRM Asphalt Paving **6/27/97**	Paver Operator (Left Side)	492	984	0.78	0.61
	Screed Operator•	496	992	0.37	0.19
	Raker/Laborer	486	996	0.69	0.44
	Mechanic	484	968	0.65	0.44
	Traffic Control✓	410	820	0.27	0.037
	Roller Operator (Breakdown)	468	959	0.054	0.042
	Roller Operator (Finish)✓	455	910	0.043	ND (<0.007)
	CRM Bag Breaker✱	447	894	0.51	0.044

mg/m^3 = Concentration, milligrams per cubic meter
ND = Not Detected (below the Minimum Detectable Concentration
† = These were modified "personal breathing zone" air samples. The sampling pump was attached to the paver operator's seat and the filter cassette oriented in the approximate breathing zone of the employee. Since the paver operator would occasionally switch sides, a sampling pump and filter was positioned on both the left and right control seat.
• = When the paver vehicle was stopped, the screed operator would also (on occasion) work as a raker.
✓ = These activities were not sampled on all four days of the survey.
✱ = This activity was performed at the HMA plant by a subcontractor hired to blend the CRM asphalt cement.

Table 11
Concentrations of Polycyclic Aromatic Compounds (PACs): Personal Breathing-Zone Samples
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Sampling Date	Work Activity	Sampling Time (minutes)	Sample Volume (Liters)	Concentration, micrograms per cubic meter			
				PACs @ 370 nm•	PACs @ 400 nm•	Other SulCom	Benzothiazole
Conventional Asphalt Paving **7/22/97**	Paver Operator (Left Side)❖	504	983	30	4.1	2.0	ND (<0.06)
	Paver Operator (Right Side)❖	390†	780	55	7.7	ND (<0.08)	ND (<0.08)
	Screed Operator	505	985	191	25	ND (<0.06)	ND (<0.06)
	Raker/Laborer	501	1027	22	2.9	ND (<0.06)	ND (<0.06)
	Roller Operator (Breakdown)	446	870	17	3.4	ND (<0.07)	ND (<0.07)
	Roller Operator (Finish)	433	844	1.2	0.12	ND (<0.07)	ND (<0.07)
Conventional Asphalt Paving **7/23/97**	Paver Operator (Left Side)❖	576	1152	68	9.5	ND (<0.05)	ND (<0.05)
	Paver Operator (Right Side)❖	576	1123	100	14	ND (<0.05)	ND (<0.05)
	Screed Operator	585	1170	27	3.8	ND (<0.05)	ND (<0.05)
	Raker/Laborer	570	1026	12	1.9	ND (<0.05)	ND (<0.05)
	Roller Operator (Breakdown)	553	1106	17	1.5	ND (<0.05)	ND (<0.05)
	Roller Operator (Finish)✦	532	1064	2.2	0.32	ND (<0.05)	ND (<0.05)
CRM Asphalt Paving **6/25/97**	Paver Operator (Left Side)	125‡	250	540	20	ND (<0.24)	108
	Screed Operator	330	660	173	6.4	ND (<0.09)	61
	Raker/Laborer	330	660	63	3.2	ND (<0.09)	17
	Raker/Laborer ✦★	327	654	124	3.5	ND (<0.09)	8.1
	Mechanic ✦	328	672	372	13	ND (<0.09)	58
	Traffic Control ✦✓	333	666	2.7	ND (<0.09)	ND (<0.09)	ND (<0.09)
	Roller Operator (Breakdown)	333	666	152	3.9	ND (<0.09)	ND (<0.09)
CRM Asphalt Paving **6/27/97**	Paver Operator (Left Side)	492	984	459	27	9.6	106
	Screed Operator	496	992	281	14	ND (<0.06)	34
	Raker/Laborer★	485	946	172	8.8	ND (<0.06)	26
	Raker/Laborer ✦	486	923	466	24	13	77
	Mechanic ✦	484	968	303	15	3.8	52
	Traffic Control ✦✓	405	810	15	0.52	ND (<0.07)	ND (<0.07)
	Roller Operator (Breakdown)	468	936	24	1.6	ND (<0.07)	ND (<0.06)
	CRM Blender Operator✱	445	935	56	5.0	ND (<0.06)	ND (<0.06)

SulCom = Other sulfur-containing compounds
370 nm = 370 nanometers, spectrofluorometric detector wavelength (includes both vapor and particulate phase)
400 nm = 400 nanometers, spectrofluorometric detector wavelength (includes both vapor and particulate phase)
❖ = These should be considered "modified personal breathing zone" air samples since a sampling pump and filter was positioned on both the left and right control seat (the paver operator would occasionally switch sides while operating the paver).
† = Sampling pump faulted after 390 minutes. The pump was not replaced.
ND = Not Detected (below the Minimum Detectable Concentration)
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 initial filter cassette became dislodged and was lost in the asphalt. It was replaced with a new filter cassette.
★ = Analytical problem may have affected the results. For this sample the actual concentration may be higher than is shown.
✦ = These work activities were not sampled for all four days of the survey.
✓ = Not a true personal breathing-zone air sample since the sampling pump and filter were placed in the cab of a work truck where the traffic control employees spent the majority of their work day.
• = The PACs concentrations reported in this table include both the particulate phase (collected on the filter) and the vapor phase (from the sorbent tube).
✱ = This activity was performed at the HMA plant by a subcontractor hired to blend the CRM asphalt cement.

Table 12
Personal Breathing-Zone Concentrations of Carbon Monoxide, expressed in ppm
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Date	Activity	Carbon monoxide (Peak)	Carbon monoxide (TWA)
6/25/97	Paver Operator	79	8
6/25/97	Roller Operator (breakdown)‡	262	12
6/25/97	Roller Operator (intermediate)‡	232	10
6/25/97	Roller Operator (finish)‡	807	11
6/27/97	Paver Operator	100	24
6/27/97	Roller Operator (breakdown)‡	58	19
6/27/97	Roller Operator (breakdown)‡	910	13
6/27/97	Roller Operator (finish)‡	237	19

ppm = parts per million
Peak = highest instantaneous exposure which was detected during the sampling period
‡ = This individual smoked cigarettes during the sampling period. Cigarette smoke contains carbon monoxide.

Table 13
Personal Noise Exposures, expressed in decibels [A-weighted, dB(A)]
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Date	**ActivityP**	**Sampling (minutes)**	**TWA Exposure (L_{eq})**	**Max Level ‡**
6/25/97	Paver Operator	302	88.8†	112.1
6/25/97	Roller Operator (Breakdown)	286	93.9†✶	115.5
6/25/97	Roller Operator (Finish)	325	92.9†✶	115.9
6/25/97	Roller Operator (Finish)	332	91.4†	109.5
6/27/97	Paver Operator	488	91.6†	116.3
6/27/97	Roller Operator (Breakdown)	461	90.0†	111.0
7/22/97	Paver Operator (Rightside)	485	92.8†	112.1
7/22/97	Paver Operator (Leftside)	440	98.9†✶	126.0
7/22/97	Roller Operator (Breakdown)	444	91.5†	112.9
7/22/97	Roller Operator (Finish)	434	84.5	111.0
7/23/97	Paver Operator (Rightside)	485	101.9†✶	124.1
7/23/97	Paver Operator (Leftside)	525	93.4†	112.1
7/23/97	Roller Operator(Finish)	523	87.2	107.6
7/23/97	Roller Operator (Breakdown)	520	89.6	116.3

P = Noise dosimeters were either worn by the worker or placed in their immediate work area
L_{eq} = Noise equivalent, calculated using a threshold of 85 dB and a 3 dB exchange rate (the NIOSH Recommended Exposure Limit)
‡ = Maximum one-minute noise level (over the sampling period)
† = Exceeds the Occupational Safety and Health Action Level for implementing a hearing conservation program
✶ = Exceeds the Occupational Safety and Health Permissible Exposure Limit for noise

Table 14
Number of Acute Symptom Questionnaires Completed by Workers
Paving Company: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Work Group		Acute Questionnaires Completed			
		6/25/97 Day 1 CRM Rubber Asphalt	6/27/97 Day 2 CRM Rubber Asphalt	7/22/97 Day 3 Conventional Asphalt	7/23/97 Day 4 Conventional Asphalt
Pavers (n=6)†		24/30*	29/30	25/30	30/30
Non-pavers (n=8)‡		33/40	31/40	28/40	32/40
Paving Period Totals	**Pavers**	53/60		55/60	
	Non-pavers	64/80		60/80	

* = Short paving work-shift provided only enough time to complete four rounds of acute questionnaires.
† = All six pavers participated in all four survey days, except for one worker who was not available on day three.
‡ = The same eight non-pavers participated in all four survey days, except for one worker who was not available on day two.

Table 15
Number of Workers Reporting Symptoms and Number of Symptom Occurrences by Survey Day
Paving Company: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Symptoms	Work Groups	Number of workers reporting symptoms (Number of symptom occurrences reported)			
		6/25/97 Day 1 CRM Asphalt	6/27/97 Day 2 CRM Asphalt	7/22/97 Day 3 Conventional Asphalt	7/23/97 Day 4 Conventional Asphalt
Dry, itching, or irritated eyes	Pavers	1 (3)	1 (4)	1 (3)	1 (3)
	Non-pavers	0	0	0	0
Stuffy, burning, or irritated nose	Pavers	1 (2)	1 (2)	2 (6)	2 (4)
	Non-pavers	0	0	1 (1)	0
Sore, dry, scratchy, or irritated throat	Pavers	3 (7)	2 (8)	0	0
	Non-pavers	0	0	0	1 (1)
Skin burning, rash, itching, or irritated	Pavers	0	0	0	0
	Non-pavers	0	0	0	0
Bothered by coughing	Pavers	0	1 (1)	0	0
	Non-pavers	0	0	1 (1)	0
Chest tightness or shortness of breath	Pavers	0	1 (1)	0	0
	Non-pavers	0	0	0	0
Wheezing or whistling in chest	Pavers	1 (2)	0	0	0
	Non-pavers	0	0	0	0
Totals	Pavers (n=6)†	3 (14)	3 (16)	3 (9)	3 (7)
	Non-pavers (n=8)‡	0	0	2 (2)	1 (1)

† = All six pavers participated in all four survey days, except for one worker who was not available on day three.
‡ = The same eight non-pavers participated in all four survey days, except for one worker who was not available on day two.

Table 16
Rate of Symptoms Occurrence Per Questionnaire Among Pavers by Survey Day
Paving Company: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Pavers‡ (n=6)	**6/25/97 Day 1 CRM Rubber Asphalt**	**6/27/97 Day 2 CRM Rubber Asphalt**	**7/22/97 Day 3 Conventional Asphalt**	**7/23/97 Day 4 Conventional Asphalt**
Completed Questionnaires	24	29	25	30
Symptom Occurrences	14	16	9	7
Rate of symptom occurrence per questionnaire	0.58	0.55	0.36	0.23
	0.57 P		0.29 P	

‡ = All six pavers participated in all four survey days, except for one worker who was not available on day three.
P = Average rate (over two days) of symptom occurrence per questionnaire

Table 17
Estimated Hours of Exposure to Asphalt Fume Among Pavers by Job Title and Survey Day
Paving Company: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Job Title (n=6)‡	**Estimated hours exposure to asphalt fume**			
	6/25/97 Day 1 CRM Rubber Asphalt	**6/27/97 Day 2 CRM Rubber Asphalt**	**7/22/97 Day 3 Conventional Asphalt**	**7/23/97 Day 4 Conventional Asphalt**
Screed Operator	5.5	7.5	7.25	7.0
Screed Operator/Raker	5.5	7.5	7.5	7.0
Raker	5.25	7.25	7.25	6.75
Raker/Dumpman	5.25	7.5	7.25	5.75
Foreman/Screed Operator	5.5	5.0	7.25	6.75
Roller Operator	6.0	7.5	absent	6.75
Daily Total Hours (Average)	33.0 (5.5)	42.25 (7.0)	36.5 (7.3)	40.0 (6.7)
Total Hours by Asphalt Type (Average)	75.25 (6.3)		76.5 (7.0)	

‡ = All six pavers participated in all four survey days, except for one worker who was not available on day three.

Table 18
Rate of Symptoms Per Hour of Exposure Among Pavers by Survey Day
Paving Company: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

Pavers (n=6)‡	**6/25/97 Day 1 CRM Rubber Asphalt**	**6/27/97 Day 2 CRM Rubber Asphalt**	**7/22/97 Day 3 Conventional Asphalt**	**7/23/97 Day 4 Conventional Asphalt**
Estimated Exposure to Asphalt (total hours)	33.0	42.25	36.5	40.0
Number Symptom Occurrences	14	16	9	7
Rate (symptom occurrence/hr exposure)	0.42	0.38	0.25	0.18
	0.40 P		0.21 P	

‡ = All six pavers participated in all four survey days, except for one worker who was not available on day three.
P = Average rate (over two days) of symptom occurrences per hour of paving exposure.

Table 19
Summary of Area Concentrations of Air Contaminants
Paving Site: Bardon-Trimount, Boston, Massachusetts (HETA 97-0232)

	Analyte	TWA Concentration, expressed in micrograms per cubic meter							
		7/22/97 Conventional		7/23/97 Conventional		6/25/97 CRM Asphalt		6/27/97 CRM Asphalt	
Air Sample Position at Screed ➜		Left	Right	Left	Right	Left	Right	Left	Right
Paver Screed	Total Particulate	1400	1400	1500	1800	6000	8800	11000	8400
	Benzene Soluble Fraction	1200	1200	1300	1600	5800	8500	9800	7500
	Total Particulate	1400	1500	1600	1900	6500	8100	12000	8700
	Benzene Soluble Fraction	1200	1200	1400	1600	6400	7700	10000	8100
	PACs$_{370}$ (vapor & particulate)	429	NS	393	281	2029	2832	2601	2027
	PACs$_{400}$ (vapor & particulate)	72	NS	77	60	130	279	192	181
	PACs$_{370}$ (vapor & particulate)	440	466	450	486	2062	2666	1853	2257
	PACs$_{400}$ (vapor & particulate)	81	97	83	88	145	273	203	177
	Benzothiazole	ND	NS	ND	ND	88	81	90	157
	Other Sulfur Compounds	95	NS	78	106	112	264	207	165
	Benzothiazole	ND	ND	ND	ND	100	233	104	179
	Other Sulfur Compounds	50	70	103	104	133	233	295	232
	Total Hydrocarbons with a retention time < toluene	1.3	2.0	2.3	2.3	4.8	16	9.9	6.0
	Total Hydrocarbons with a retention time > toluene	15	23	24	24	71	224	126	86
	Respirable Particulate	440	590	580	770	2500	4800	4600	3000
Highway Backgnd.	Total Particulate‡	0.029		0.030		0.074		0.033	
	Benzene Soluble Fraction‡	ND (<0.008)		0.012		ND (<0.010)		0.019	
	PACs$_{370}$ (vapor & particulate)	2.7		ND (<0.06)		10		7.0	
	PACs$_{400}$ (vapor & particulate)	0.32		ND (<0.06)		ND (<0.09)		ND (<0.07)	
	Benzothiazole	ND (<0.08)		ND (<0.06)		ND (<0.09)		ND (<0.07)	
	Other Sulfur Compounds	ND (<0.08)		ND (<0.06)		ND (<0.09)		ND (<0.07)	
	Respirable Particulate	0.88		0.11		0.072		ND (<0.03)	

PAC$_{370}$ = Polycyclic aromatic compound measured with 370 nanometer wavelength detector
PAC$_{400}$ = Polycyclic aromatic compound measured with 400 nanometer wavelength detector
ND = Not Detected (below the Minimum Detectable Concentration which is shown in brackets)
‡ = Average of three highway background samples