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Staker Construction Company
Casa Grande, Arizona

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PREFACE

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

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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 Casa Grande, Arizona, during asphalt pavement construction along Interstate 8. 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 Arizona project.

On February 27 and 29, 1996, approximately 4,400 metric tons of conventional asphalt were applied by the Staker Construction Company; on March 20 and 21, 1996, approximately 5,400 metric tons of CRM asphalt were placed by the same workers. The rubber content was approximately 18.5% of the asphalt binder by weight. The workplace exposure and health assessment were performed during all four paving days. The evaluation included the collection of area air samples to characterize the asphalt fume emission, personal breathing zone (PBZ) air samples to evaluate worker exposures, and a medical component that included symptom questionnaires and lung function tests.

Asphalt fume exposures have typically been measured as total particulate (TP) and the benzene soluble particulate fraction (BSF). However, since neither of these exposure markers measure exposure to a distinct chemical component or even a distinct class of chemicals, it is difficult to relate them to possible health effects. For example, many organic compounds are soluble in benzene, and any dust may contribute to TP levels. In an effort to address this problem, new or modified analytical methods were developed and included in this study to more definitively characterize asphalt fume exposures. Polycyclic aromatic compounds (PACs), which may be present in asphalt fume, were measured using a new analytical method. Some of the PACs may have irritative effects, while other PACs are suspected to be carcinogenic. In addition to PACs, benzothiazole (a sulfur–containing compound present in rubber tires), along with other sulfur–containing compounds (suspected to be present as a result of the addition of rubber to the asphalt or from crude petroleum used for asphalt manufacturing) were also measured. Benzothiazole is of interest since it may be useful as a surrogate indicator for other CRM asphalt fume exposures while other sulfur–containing compounds may be associated with respiratory irritation. Samples were collected for analysis of selected 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), sulfur dioxide (SO_2), and ozone (O_3). Finally, bulk air samples of asphalt fume were collected at the asphalt cement storage tank located at the hot mix asphalt plant and submitted for mutagenicity testing.

The concentrations of TP, respirable particulate, and BSF varied between sampling locations and across survey days but generally were higher during the CRM asphalt paving periods than during conventional asphalt paving periods. At the paver screed area sample locations, concentrations of total PAC, and those of sulfur–containing compounds (except benzothiazole), were approximately two times higher during CRM asphalt paving as compared to conventional asphalt paving. With the exception of three area samples, benzothiazole was detected only during CRM asphalt paving.

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 all present at concentrations which were less than 1 part per million (ppm). Total hydrocarbon concentrations, quantified as either n–hexane or Stoddard solvent, ranged from 0.42 to 111 milligrams per cubic meter (mg/m^3). All of these concentrations are orders of magnitude below their respective occupational exposure limits. Concentrations of benzene ranged from less than 0.019 to 0.4 ppm. While these benzene concentrations do not represent personal exposures, they do suggest the potential for employee exposure. NIOSH classifies benzene as an occupational carcinogen and recommends that occupational exposures be reduced to the lowest feasible concentration.

Short–term CO concentrations ranging up to approximately 100 ppm were measured near the paving site when a gasoline–powered vibrating tamper was used to compact the asphalt around roadside objects (such as guardrails and sign posts). The NIOSH recommended exposure limit (REL) for CO is an 8–hour time–weighted average (TWA) of 35 ppm and a ceiling limit (never to be exceeded even momentarily) of 200 ppm. Concentrations of H_2S, SO_2, and O_3 were well below their respective occupational exposure limits.

Personal breathing–zone air samples were collected daily on six to eight workers during the four sampling days. The PBZ samples were analyzed for TP, BSF, total PACs, benzothiazole, and other sulfur–containing compounds. The PBZ exposures for TP ranged from 0.02 to 1.03 mg/m^3 during conventional asphalt paving, and from 0.03 to 0.6 mg/m^3 during CRM asphalt paving. Although TP concentrations were typically higher during conventional asphalt paving, the accuracy of this difference cannot be easily determined due to the limited number of PBZ samples collected in this one evaluation. All of the PBZ concentrations were well below the current NIOSH REL for asphalt fume of 5 mg/m^3 (measured as TP).

Personal breathing–zone concentrations of PACs (at analytical emission wavelengths of 370 and 400 nanometers) and other sulfur–containing compounds were generally higher during CRM asphalt paving when compared to conventional asphalt paving. The PBZ concentrations of PAC_{370} during conventional and CRM asphalt paving ranged up to 2.8 and 8.7 µg/m^3, respectively. With the exception of one PBZ sample, benzothiazole was detected only during CRM asphalt paving operations, ranging up to 44 µg/m^3.

Eight workers with exposure to the asphalt paving operation (pavers) were recruited for the health assessment. Additionally, eight workers not typically exposed to hot asphalt fume (non–pavers) were recruited for comparison. Serial symptom questionnaires were administered to obtain information concerning the prevalence of acute symptoms (i.e., respiratory, eye, nose, throat, and skin symptoms) in relation to worksite exposures. Serial measurements of peak expiratory flow rate (PEFR) were conducted to evaluate acute changes in lung function in relation to worksite exposures. Two pavers were excluded from analysis due to lack of exposure to the paving operation on the last two survey days and two non–pavers were excluded due to ongoing flu–like illness during the health assessment.

Among the six remaining non–pavers, the most frequently reported symptoms (as a percentage of occurrences over all four days) were nasal irritation (52%), cough (26%), throat irritation (18%), and eye irritation (4%). Among the remaining six pavers, the most frequently reported symptoms (as a percentage of occurrences over all four days) were nasal irritation (39%), throat irritation (22%), eye irritation (15%), cough (14%), and skin irritation (10%). There were no appreciable changes between the conventional and CRM asphalt paving periods in the types of symptoms reported. Among pavers, 94% of the symptoms were reported during ongoing or recent exposure to asphalt fumes, and 99% of the symptoms reported were rated as “mild” in severity (the choices were “mild,” “moderate,” or “severe”).

The symptom survey revealed little difference between the conventional and the CRM asphalt paving periods with respect to the *number of symptoms reported, the rate of symptom occurrences per completed questionnaire, or the rate of symptom occurrences per self–reported hour of asphalt paving exposure*. Acute irritant symptoms were reported by workers in association with work site exposures, and for one worker (paver), the reported symptoms were accompanied by significant bronchial lability on one survey day.

This study showed that PBZ exposures to asphalt fume emissions, as well as other exposure measurements, were below current NIOSH RELs and other relevant exposure limits for those substances that have them. For the area samples, concentrations of TP, respirable particulate, BSF, PACs, and other sulfur–containing compounds (except benzothiazole) were higher during CRM asphalt paving than during conventional paving. 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. Despite the observed differences in exposure between the conventional and CRM asphalt paving periods, there was little difference in symptom rates or types of symptoms reported between the conventional and CRM paving periods. One paver demonstrated increased bronchoreactivity during one of the survey days, but the occupational contribution to this finding is unclear at this time. It is premature to draw definitive conclusions from this single site evaluation. Data provided from this evaluation are from a very small sample size and may reflect production and weather conditions specific to this site. Data from additional site evaluations may enable more definitive conclusions to be drawn. A final composite report will be prepared after these additional site evaluations are completed.

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

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PROCESS OVERVIEW

There are three basic steps in constructing an asphalt pavement – manufacture of the hot mix asphalt (HMA), placement of the mix onto the ground, and compaction. The asphalt mix contains two primary ingredients, a binder which is typically an asphalt cement, and an aggregate which is usually a mixture of coarse and fine stones, gravel, sand, and other mineral fillers. The mix design establishes the proportions 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 February 27 and 29, and continuing on March 20 and 21, 1996, NIOSH investigators conducted a study near Casa Grande, Arizona, during asphalt pavement construction on Interstate 8 by the Staker Construction Company. The same paving crew was evaluated throughout the survey and consisted of a foreman, a truck dumper, a paver operator, a screed operator, a traffic control person, and two to three roller operators.

During this survey, both the conventional hot mix asphalt (hereafter referred to as "conventional asphalt") and crumb rubber modified hot mix asphalt (subsequently referred to as "CRM asphalt") were manufactured at the same plant from the same petroleum crude source. The conventional asphalt was placed on February 27 and 29 while the CRM asphalt was used on March 20 and 21. All of the paving occurred on traffic lanes or shoulders with the traffic diverted to adjacent lanes.

A summary of the paving activities and equipment used at the I–8 site is contained in Table 1. Both the conventional and CRM paving projects used a 19-millimeter (mm) maximum grade hot mix asphalt. The crude supplier was Eott Paramount, and the granulated rubber was manufactured by the Baker Rubber Company. A viscosity graded asphalt cement, AC–40, was used for the conventional asphalt, while an AC–10 was used in the CRM asphalt paving. Although the CRM asphalt design mix allowed up to 22% rubber (total weight of rubber by the total weight of the asphalt/rubber blend), the actual rubber content on March 20–21 was approximately 18.5%.

The portable HMA plant used for this construction project was located adjacent to the interstate highway and was approximately 10 to 20 minutes from the I–8 paving site (the distance traveled by the asphalt delivery trucks varied somewhat depending on which portion of the highway was currently being paved). The HMA was hauled to the paving site by belly dump trailer trucks (each trailer averaged approximately 21 metric tons [23 short tons].

The conventional asphalt was used to construct a base course for the shoulder lane (February 27 and 29) and a base course for the shoulder (February 29 only). The CRM asphalt was used to construct a base course for both the shoulder lane and shoulder on March 20–21. Approximately 4,400 metric tons of conventional asphalt were applied on February 27 and 29, compared to 5,400 metric tons of CRM asphalt placed on March 20–21. The average asphalt laydown temperature ranged from 141 to 146°C (285 to 295°F) for the conventional paving. The laydown temperature during CRM asphalt paving was 149°C (300°F). 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).

The bottom dump trailers placed the hot asphalt material onto the road in a windrow channel approximately 1.2 meters (4 ft.) wide and 0.6 meters (2 ft.) high. The paver, following behind the trucks, used a windrow conveyor to pick–up the asphalt from the road, load it into its hopper, and then place the asphalt with a screed attachment.

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

Personal Breathing–Zone Air Samples

Personal breathing–zone (PBZ) monitoring was conducted on most of the 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).

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. 5040 for elemental carbon.

MEDICAL EVALUATION DESIGN

On February 26, NIOSH investigators recruited workers to participate in the health assessment, which included a general health and occupational history questionnaire, serial acute symptom questionnaires, and serial peak expiratory flow rate (PEFR) testing. 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.

All workers with exposure to the asphalt paving operation (pavers) were asked to participate in the study. All eight pavers volunteered and were included in the health assessment. NIOSH investigators also recruited eight workers employed at the same construction site, but not in proximity to the asphalt paving operation (non–pavers), to participate in the health assessment for comparison purposes.

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 work shift and three times during the work shift, 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 time–weighted average (TWA). Personal exposures can be expressed in parts per million (ppm), milligrams per cubic meter (mg/m^3), or micrograms per cubic meter (µg/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.

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. One obvious difference between the conventional and CRM asphalt paving periods in this study was the weather. The ambient temperatures during the conventional asphalt paving sampling (which occurred in February) were cooler than during the CRM asphalt, which occurred a month later. For example, the low and high temperatures for each of the four survey days were as follows: 11 to 18°C (52 to 64°F); 11 to 19°C (52 to 67°F); 25 to 33°C (76 to 92°F); 27 to 31°C (80 to 88°F). Along with the cooler temperatures, the paving days in February were more overcast and windy.

Wind speed and direction are particularly important factors that may influence the air sampling results. As shown in Table 4, the wind direction was generally from the north/northeast and did not vary much throughout the day. The strongest winds were observed February 29, although on all days at least a slight wind was detected. Some of the paving crew, especially the truck dumper, paver operator, and traffic controller, often appeared to be downwind from the asphalt fume emissions. In contrast, all of the roller operators generally appeared to be on the upwind side of the asphalt fume emissions.

Process Information

The average production rate (number of tons of asphalt paved per hour) was very consistent over all four survey days, ranging from approximately 250 to 330 metric tons/hour. The proximity of the HMA plant to the paving sites, the method of asphalt conveyance, and the experience of the paving crew and the HMA plant employees with handling CRM asphalt resulted in nearly continuous paving days with very little down time.

Area Air Samples

Total Particulate and Respirable Particulate

Tables 5 and 6 provide the results for the total and respirable particulate concentrations, respectively. Most of the TP concentrations were below the NIOSH REL of 5 mg/m^3. At the paver screed the TP concentrations ranged from 0.07 to 5.5 mg/m^3 and from 2.7 to 6.3 mg/m^3, for conventional and CRM asphalt paving, respectively. The highest TP concentrations for both asphalt types were observed above the screed auger. The TP background concentrations measured during this survey ranged from 0.01 to 0.21 mg/m^3 but only one of the 12 TP background samples exceeded 0.05 mg/m^3.

The highest respirable particulate concentration (1.8 mg/m^3) was obtained over the screed during CRM asphalt paving. All of the remaining respirable particulate concentrations collected near asphalt fume emission areas ranged from 0.63 to 0.98 mg/m^3 (conventional asphalt paving) and 0.46 to 1.8 mg/m^3 (CRM asphalt paving). The background respirable particulate concentrations ranged from not detected (<0.02 mg/m^3) to 0.04 mg/m^3.

Benzene Soluble Particulate Fraction

As summarized in Table 5, BSF concentrations at the paver screed ranged from 0.05 to 5.1 mg/m^3 during conventional paving and from 2.6 to 6.1 mg/m^3 during CRM asphalt paving. Overall, the highest average BSF concentrations were measured during CRM asphalt paving. Presently, there are no occupational exposure criteria for the benzene soluble particulate fraction of asphalt fume from NIOSH or OSHA.

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 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. Higher concentrations of PACs were measured during CRM than during conventional asphalt paving. For example, the concentration of total PAC_{370} at the paver screed ranged from 121 to 280 $\mu g/m^3$ for conventional and from 158 to 639 $\mu g/m^3$ for CRM asphalt. The total PAC_{400} concentrations from these same samples ranged from 19 to 80 and from 23 to 113 $\mu g/m^3$, 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 criteria for total PACs, as a class, are presently unavailable from either NIOSH, OSHA, or ACGIH.

Table 7 also presents the sulfur compounds and benzothiazole concentrations obtained from hexane extracts of PAC samples which were analyzed by gas chromatography with sulfur chemiluminescence detection. Benzothiazole, an additive used in tire manufacturing, was unexpectedly detected during conventional asphalt paving in three of eight area samples collected at the paver screed (concentrations ranged from not detected [<0.35 $\mu g/m^3$] to 2.7 $\mu g/m^3$. Benzothiazole concentrations during CRM asphalt paving, however, were much higher, ranging from 21 to 83 $\mu g/m^3$. The background benzothiazole levels were all not detected (<0.29 $\mu g/m^3$). These results suggest that the CRM asphalt formulation is much more important than conventional asphalt for generating 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 110 to 258 $\mu g/m^3$) than during CRM asphalt paving (range 195 to 739 $\mu g/m^3$). The average concentration of sulfur compounds over the screed auger during conventional asphalt paving was 181 $\mu g/m^3$; the average during CRM asphalt paving was approximately twice as high (354 $\mu g/m^3$).

Elemental and Organic Carbon

Elemental and organic carbon analytical results are provided in Table 8. All but one of the air samples collected for EC above the screed auger on the paver vehicle were above the background concentrations. The EC:TC ratio, however, ranged from 0.02% to 0.22% 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 much lower 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 both the conventional asphalt and CRM asphalt paving periods. The qualitative GC/MS analysis identified over 50 VOCs. However, only the most significant peaks (benzene, toluene, xylene, MIBK, and total hydrocarbons) were quantitatively analyzed by GC/FID. The quantities of VOCs (except benzene, see next paragraph) detected at emission sources were well below their respective occupational exposure limits recommended by NIOSH, OSHA, or ACGIH. With the exception of xylene (which was detected in similar concentrations during all four sampling days), higher VOC concentrations were measured during CRM asphalt paving. Total hydrocarbons quantified as either n–hexane or as Stoddard solvent averaged 1.4 mg/m^3 and 51 mg/m^3, respectively. Both of these average concentrations are well below occupational exposure criteria for n–hexane and Stoddard solvent.

During conventional asphalt paving, the benzene concentrations ranged from trace (between 0.006 and 0.018 ppm) to 0.025 ppm. During CRM asphalt paving, benzene was present in higher concentrations, ranging from 0.019 to 0.055 ppm. Although these 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), Carbon Monoxide (CO), and Ozone (O_3)

Concentrations of H_2S, SO_2, and O_3 were screened using direct reading instrumentation. All of these compounds were present in very low concentrations and were well below their respective occupational exposure criteria. Hydrogen sulfide concentrations were not detected and SO_2 concentrations near the screed were usually not detected (with a few readings of 2 ppm). Background O_3 concentrations were less than 0.01 ppm.

Short–term, instantaneous CO concentrations as high as approximately 100 ppm were measured along the paving site when a gasoline–powered vibrating tamper was being used by laborers to compact the asphalt around roadside objects (such as guardrails and sign posts).[1] Carbon monoxide concentrations ranging between 40 to 60 ppm were measured approximately 15 feet downwind from this vibrating tamper, periodically exposing the traffic control person, screed operator, and (occasionally) the paver foreman. The NIOSH REL for CO is an 8–hour TWA of 35 ppm and a ceiling limit (never to be exceeded even momentarily) of 200 ppm.

Personal Breathing Zone Air Samples

Table 10 presents the PBZ monitoring results for TP and BSF collected 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. The TWA–actual PBZ exposure to TP ranged from 0.02 to 1.03 mg/m^3 and from 0.03 to 0.60 mg/m^3 during conventional and CRM asphalt paving, respectively. As expected, the average TP concentrations measured on the truck dumper, paver operator, and screed operator (jobs in closest proximity to fume emissions from either the paver or the asphalt delivery trucks) were among the highest exposures, averaging 0.59 mg/m^3 on conventional asphalt days and 0.28 mg/m^3 on CRM asphalt paving days. Although TP concentrations appeared to be consistently higher during conventional asphalt paving than during CRM asphalt paving, a conclusion regarding this difference cannot be determined 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 conventional asphalt paving as compared to CRM asphalt application. For example, the average BSF concentrations of the jobs in closest proximity to fume emissions from either the paver or the asphalt delivery trucks (truck dumper, paver operator, and screed operator) were approximately four times higher on conventional asphalt paving days than during CRM asphalt paving (0.43 mg/m^3 versus 0.11 mg/m^3, respectively).

Table 11 contains the PBZ results for PACs, benzothiazole, and sulfur compounds. In every

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[1] It was not possible in this survey to determine if the gasoline-powered engine on the vibrating tamper was properly tuned.

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. 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. Although PAC_{370} concentrations varied daily, they were generally higher during conventional (range: 0.2 to 49 $\mu g/m^3$) versus CRM (range: trace amount to 30 $\mu g/m^3$) asphalt paving. Occupational exposure criteria for total PACs, as a class, are presently unavailable from either NIOSH, OSHA, or ACGIH.

Except for one air sample collected on the paver operator during conventional asphalt paving (concentration = 1.0 $\mu g/m^3$), benzothiazole was detected only during CRM asphalt paving, ranging up to 44 $\mu g/m^3$. This was anticipated since benzothiazole is a sulfur–containing compound present in rubber tires. Personal breathing–zone exposures to *other* sulfur–containing compounds during conventional and CRM asphalt paving ranged from not detected (<0.71 $\mu g/m^3$) to 35 $\mu g/m^3$ and not detected (<0.7 $\mu g/m^3$) to 42 $\mu g/m^3$, respectively.

MEDICAL RESULTS

The eight non–pavers recruited for the health assessment included one project supervisor, two traffic controllers, two laborers, two truck drivers, and one heavy equipment operator. Two non–pavers (a heavy equipment operator and a laborer) were excluded from analysis of the medical data due to an ongoing flu–like illness during the health assessment. The six remaining non–pavers participated in the study for all four survey days.

The eight pavers recruited for the health assessment included one paver operator, one screed operator, one traffic controller (worked alongside paver), one dump person (manually operated controls on the bottom dump asphalt delivery trailers to place the hot mix asphalt in a windrow for subsequent pick–up by the paver), two roller operators, one quality control tester (tested hot pavement to ensure specifications), and one paving foreman. Two pavers (a quality control tester and a paving foreman) were excluded from analysis of the medical data due to lack of exposure to the paving operation on the last two survey days. The six remaining pavers participated in the study for all four survey days.

All results below pertain only to the six non–pavers and six pavers for whom data were analyzed. All six of the non–pavers were male and the average age of this group was 41 years (range 20–56 years). Three of the six pavers were male and the average age of the group was 41 years (range 29–58 years). Two of the non–pavers currently smoked cigarettes (both smoked during work), one smoked very infrequently (did not smoke during the study period), two were former smokers, and one never smoked. Two of the pavers currently smoked cigarettes (both smoked during work), three never smoked, and one was a former smoker.

The number of acute symptom questionnaires completed (i.e., the number of opportunities a worker had to report a health symptom) varied somewhat among the non–pavers and pavers (Table 12). For each group (non–pavers and pavers), a maximum of 30 (six workers times five questionnaires/day) questionnaires could have been completed during each survey day. The non–pavers completed 55 (92%) questionnaires during the first two study days and 58 (97%) during the last two study days. The pavers completed all 120 (100%) questionnaires possible during the four–day survey period.

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

Table 13 shows the number of workers reporting a health symptom at any time during a survey day. Also shown is the number of symptom occurrences reported during the survey day. Among non–pavers, 23 symptom occurrences were reported during the survey period. Three non–pavers reported 19 symptom occurrences (83%) on the first two survey days compared with two workers reporting only four symptom occurrences (17%) during the last two survey days. Among the non–pavers, the most frequently reported symptoms (as a percentage of occurrences over all four days) were nasal irritation (52%), cough (26%), throat irritation (17%), and eye irritation (4%). Among pavers, there were 78 symptom occurrences reported during the survey period. Four pavers reported 37 symptom occurrences (47%) on the first two survey days (conventional paving period) compared with four workers reporting 41 symptom occurrences (53%) during the last two survey days (CRM paving period). Among the pavers, the most frequently reported symptoms (as a percentage of occurrences over all four days) were nasal irritation (38%), throat irritation (22%), eye irritation (15%), cough (14%), and skin irritation (10%). One paver reported a mild, chronic wheezing condition which was always present (both at work and at home) and did not change over the survey days. Since this worker's wheezing symptoms were of a chronic and unchanging nature they were not counted as reportable symptom occurrences in this analysis (other types of symptoms, if present, were counted). There were no appreciable changes between the conventional and CRM asphalt paving periods in the types of symptoms reported. Ninety–four percent (73/78) of the pavers' symptoms were reported during ongoing or recent exposure to asphalt fumes. Ninety–nine percent (77/78) of the symptoms reported by the pavers were rated as "mild" in severity (the choices were "mild," "moderate," or "severe").

The *rate* of reported symptom occurrences per completed questionnaire (defined as the *number of symptom occurrences* divided by the *number of completed questionnaires*) among pavers by survey day is presented in Table 14. The symptom reporting rate increased slightly (approximately 10 percent) from 0.62 symptoms per completed questionnaire during the conventional asphalt paving period to 0.68 symptoms per completed questionnaire during the CRM asphalt paving period.

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 15 shows each paver's estimated exposure time to asphalt paving for each survey day. The average estimated hours of exposure to asphalt paving was higher during the CRM asphalt paving period. Workers had a combined average of 7.3 hours of exposure/day to the paving operation during the conventional asphalt paving period, compared to a combined average exposure of 8.3 hours/day during the CRM asphalt paving period. All non–pavers reported no exposure to asphalt paving at any time during the survey period.

The *rate* of reported symptom occurrences per hour of estimated exposure to asphalt fume (defined as the *number of symptom occurrences* divided by the *number of hours of estimated exposure*) was calculated for the pavers for each survey day (Table 16). The rates of symptom occurrences per hour of exposure among pavers were similar for the conventional asphalt paving period (0.43 symptom occurrences per hour of exposure) and the CRM asphalt paving period (0.41 symptom occurrences per hour of exposure).

The PEFR measurements revealed that one worker, a paver, demonstrated a change consistent 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 survey day 4. This worker showed a worsening in PEFR over the course of the workday, a pattern that is often seen with work–related bronchial lability.

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 19°C [64 to 67°F]) were cooler than the air temperatures recorded during the CRM asphalt paving period (31 to 33°C [88 to 92°F]). Based on the limited number of air samples collected during this site survey, however, 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/northwest at speeds ranging from 3 to 11 miles per hour (mph). Although the extent that these weather conditions influenced the air sampling results is uncertain, based on the direction of the paver (from east to west on all four paving days) and the movement of the asphalt plume, some members of the paving crew, such as the truck dumper, paver operator, screed operator (and, occasionally, the traffic control person) would have always been downwind of the asphalt fume. Laborers and roller operators were generally working upwind of the asphalt fumes during the four paving days surveyed.

Process Information

There were few significant differences between the conventional and CRM asphalt paving construction projects during this survey. The average production rate (number of tons of asphalt paved per hour) was very consistent over all four survey days, ranging from approximately 250 to 330 metric tons/hour. The proximity of the HMA plant to the paving sites, the method of asphalt conveyance, and the experience of the paving crew and the HMA plant employees with handling both conventional and CRM asphalt resulted in nearly continuous paving days with very little down time.

Air Sampling

The current NIOSH REL for asphalt fume is 5 mg/m^3, measured as TP. All of the PBZ samples, and most of the area samples collected adjacent to emission sources, were below this limit. However, it is important to realize that exposure criteria 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, VOCs (i.e, toluene, xylene, MIBK, petroleum distillates, etc.) detected above the screed auger were well below any existing occupational exposure limits. During CRM asphalt paving benzene concentrations ranged from 0.019 to 0.4 ppm (concentrations during conventional asphalt paving were 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 17 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 area concentrations were similar during conventional and CRM asphalt paving.

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

P As may be expected, the average TP PBZ concentrations measured on the truck dumper, paver operator, and screed operator (those jobs in closest proximity to fume emissions from either the paver or the asphalt delivery trucks) were among the highest exposures, averaging 0.59 mg/m^3 on conventional asphalt paving days and 0.28 mg/m^3 on CRM asphalt paving days.

P Although TP PBZ concentrations appeared to be consistently higher during conventional asphalt paving than during CRM 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 contributing to the results of area and PBZ samples collected 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 nanometers [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 110 to 258 μg/m^3) than during CRM asphalt paving (range 195 to 739 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) measured during conventional and CRM asphalt paving were similar.

P Except for four air samples (three area, one PBZ), 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.

Medical

The results of the acute symptom survey revealed little difference between the conventional asphalt paving period and the CRM asphalt paving period with respect to 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 exposure*. Among non–pavers, 83% (19/23) of the symptom occurrences were reported during the first two survey days (conventional asphalt paving period). This finding suggests that unidentified factors may have affected symptom rates and, if present among pavers, could thus have obscured our ablity to detect differences related to the type of asphalt exposure.

Evaluation of acute symptoms in combination with peak flow testing was performed to determine whether acute irritant effects of the airways (as measured by symptom reporting) were associated with intermittent or reversible bronchospastic responses. Acute irritant symptoms were reported by workers in association with work site exposures, and for one worker (paver), the reported symptoms were accompanied by significant bronchial lability on one survey day. Various occupational and non–occupational conditions can affect the results of pulmonary function tests. Cigarette–related bronchitis and emphysema are probably the most common cause of pulmonary function abnormalities among adults. Also, certain occupational chemical and dust exposures can cause or contribute to pulmonary function abnormalities. The few studies that have examined the respiratory effects from exposure to asphalt fumes have not reported exposure-related pulmonary function abnormalities. The extent to which occupational exposures may have contributed to this individual's findings, if any, is unknown. Continuing evaluation of the relationship between reported symptoms, bronchoreactivity, and environmental measurements indicative of workers' asphalt fume exposure will be conducted as additional data become available from other study sites. Upon completion of the entire study, a composite report evaluating and analyzing the data taken from each of the individual reports will be issued.

CONCLUSIONS

Results presented here apply only to this survey and cannot be generalized to indicate the exposures or health effects associated with CRM asphalt paving. This study showed that 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 occupational exposure criteria). 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. Despite the observed differences in exposure between the conventional and CRM asphalt paving periods, there was little difference in symptom rates or types of symptoms reported between the conventional and CRM paving periods. One paver demonstrated increased bronchoreactivity during one of the survey days, but the occupational contribution to this finding is unclear at this time. Data from this evaluation are based on a very small sample size and may reflect production and weather conditions specific to this site. Additional site evaluations may increase our ability to understand and interpret observations made at this site and should lead to more definitive conclusions.

RECOMMENDATIONS

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

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

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

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

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

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

6. All workers should wear protective clothing or appropriate sunscreen to shield exposed skin surfaces from the harmful ultraviolet component of sunlight.
7. Over the course of this survey workers were observed performing a number of job tasks which could potentially lead to musculoskeletal injury. Employees performing manual lifting and shoveling should be taught appropriate lifting techniques and be provided with the appropriate equipment to minimize musculoskeletal strain.

ABBREVIATIONS AND TERMS

ACGIH	American Conference of Governmental Industrial Hygienists
BSF	Benzene soluble (particulate) fraction
C	Ceiling, an exposure that shall not be exceeded during any part of the workday
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
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
$\mu g/m^3$	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

ELEMENTAL CARBON (DIESEL EXHAUST) 5040

C MW: 12.01 CAS: none RTECS: none

METHOD: 5040, Issue 1 **EVALUATION: PARTIAL** **Issue 1: 15 March 1996**

OSHA : **NIOSH:** **ACGIH:**	see APPENDIX A	**PROPERTIES:**	nonvolatile solid; MP >350 °C

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

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 ≥ 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):

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

EVALUATION OF METHOD:

Currently, a suitable EC standard reference material is not available for verification of the accuracy of the method in the determination of EC. For this reason, only the accuracy of the method in the analysis of various OC standards and carbonaceous dusts for total carbon could be examined [1]. A commercial instrument was used for method evaluation [5]. No discernable differences in the responses of five different compounds were noted. Linear regression of the data for all five compounds gave a slope and correlation coefficient near unity [**m** = 0.99 (± 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 σ_y/**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 + 3σ_{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:

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

APPENDIX A.

Diesel exhaust has been classified by IARC as a probable human carcinogen [8]. NIOSH has recommended "...that whole diesel exhaust be regarded as a potential occupational carcinogen..." and that workers' exposures be reduced[9,10]. The American Conference of Governmental Hygienists (ACGIH) has proposed a TWA of 0.15 mg/m^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 µg/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.

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

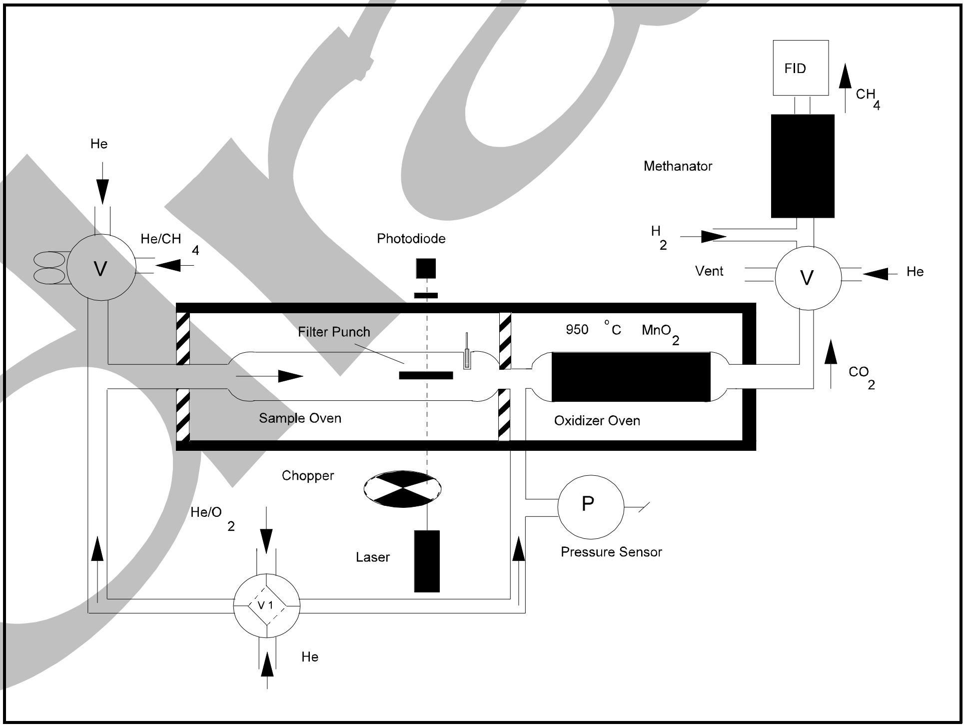

Figure 1. Schematic of Thermal–Optical Analyzer.

Table 1
Production and Equipment Information for I–8 Project
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96–0072)

Description	2/27/96 Conventional	2/29/96 Conventional	3/20/96 CRM	3/21/96 CRM
Pavement Function	Base course for truck lane	Base course for truck lane & emergency lane	Base course for truck lane & emergency lane	Base course for truck lane & emergency lane
Hot Mix Asphalt Type	Conventional 19 millimeter (3/4') maximum grade	Conventional 19 millimeter (3/4') maximum grade	CRM asphalt 19 millimeter (3/4') maximum grade	CRM asphalt 19 millimeter (3/4') maximum grade
Crude Supplier	Eott Paramount	Eott Paramount	Eott Paramount	Eott Paramount
Asphalt Cement Grade	AC-40	AC-40	AC-10	AC-10
% Binder Content	5.2	5.2	6.2	6.2
% Rubber (total weight of rubber by total weight of asphalt/rubber blend)	NA	NA	18.5%‡ (Supplier: Baker Rubber, South Bend, IN)	18.5%‡ (Supplier: Baker Rubber, South Bend, IN)
Rubber Blending	NA	NA	Wet Method	Wet Method
Production, in metric tons	1,978 (2,180 short tons)	2,425 (2,673 short tons)	2,800 (3,087 short tons)	2,631 (2,900 short tons)
Asphalt Laydown Temperature (estimated)	141°C (285°F)	146°C (295°F)	149°C (300°F)	149°C (300°F)
Mat Thickness (uncompacted)	6.4 centimeters	6.4 centimeters	6.4 centimeters	6.4 centimeters
Laydown Width (Approximation)	4.6 meters (15 feet)	3.4 meters (11 feet)	3.4 meters (11 feet)	3.4 meters (11 feet)
Hot Mix Asphalt Conveyance	Bottom dump trailers (average capacity 21 metric tons) ; windrow pick–up into hopper	Bottom dump trailers (average capacity 21 metric tons) ; windrow pick–up into hopper	Bottom dump trailers (average capacity 21 metric tons) ; windrow pick–up into hopper	Bottom dump trailers (average capacity 21 metric tons) ; windrow pick–up into hopper
Job Duration (Approximation)	8 hours	8.25 hours	9 hours	8 hours
Transport	Bottom dump double trailers (25 ton capacity per truck)	Bottom dump double trailers (25 ton capacity per truck)	Bottom dump double trailers (25 ton capacity per truck)	Bottom dump double trailers (25 ton capacity per truck)
Windrower Pick–up	Yes	Yes	Yes	Yes
Paver	Barber Greene Model BG 270B Series Paver w/ windrower pick-upP	Barber Greene Model BG 270B Series Paver w/ windrower pick-up	Barber Greene Model BG 270B Series Paver w/ windrower pick-up	Barber Greene Model BG 270B Series Paver w/ windrower pick-up
Roller (joint pinch)	No	No	No	No
Roller (breakdown)	Yes	Yes	Yes (two used)	Yes
Roller (finishing)	Yes	Yes	Yes	Yes
Other Roller	Yes (rumble strip)	Yes (rumble strip)	Yes (rumble strip)	Yes (rumble strip)
Average Production Rate	247 metric tons/hour	294 metric tons/hour	311 metric tons/hour	329 metric tons/hour

P On February 27, 1996, two pavers were used by Staker Construction. The first paver was manufactured by Blaw-Knox (no model number). After lunch, the paving crew switched to the Barber Greene Model BG 270B paver for the remainder of their work day.

‡ The actual rubber content on 3/20 &3/21 was 18.5%; however, the asphalt mix design for this project allowed up to 22% rubber.

Table 2
Summary of Sampling and Analytical Methods
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

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 NIOSH asphalt paving surveys conducted prior to this evaluation, a glass fiber filter was used.	OSHA Method No. 58, with modifications. 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.
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 draft copy of NIOSH Method 5040 is provided as Appendix B.
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).
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.

Table 2
Summary of Sampling and Analytical Methods
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

Substance	Flow Rate (Lpm)	Sample Media	Analytical Method	Comments
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.

‡ In this evaluation a new sampling and analytical technique 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. Used previously in HETA 95-0307-2602, this new combination method has yet to be assigned a NIOSH sampling and analytical method number .

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: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

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: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

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: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

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: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

Description	**2/27/96 Conventional Asphalt**	**2/29/96 Conventional Asphalt**	**3/20/96 CRM Asphalt**	**3/21/96 CRM Asphalt**
Summary	Cool and partially overcast. The temperatures in the early morning were in the lower 50's, warming to the mid 60's by the afternoon.	Cool and overcast in the morning. The temperatures in the early morning were in the lower 50's, warming to the mid 60's by the afternoon.	Sunny and warmer weather conditions than during conventional asphalt paving in February.	Sunny and warmer weather conditions than during conventional asphalt paving in February.
Minimum Temperature	11°C (52°F)	11°C (52°F)	25°C (76°F)	27°C (80°F)
Maximum Temperature	18°C (64°F)	19°C (67°F)	33°C (92°F)	31°C (88°F)
Humidity (Range)	20 to 50%	20 to 45%	8 to 17%	9 to 14%
Humidity (Average)	31%	31%	13%	12%
Minimum $\mathrm{WBGT}_{\mathrm{OUT}}$	44.0°F	41.0°F	63.1°F	63.2°F
Maximum $\mathrm{WBGT}_{\mathrm{OUT}}$	48.5°F	49.7°F	73.3°F	74.4°F
Wind Speed	Not Obtained†	6 to 11 mph	4 to 8 mph	3 to 5 mph
Wind Direction‡	Not Obtained†	270^0 to 350^0 (Winds from the north and northwest)	20^0 to 50^0 (morning) 320^0 to 360^0 (afternoon) (Winds predomninately from the north)	20^0 to 310^0 (throughout the day) (Winds were predominately from the north and northwest)
Estimated Traffic Density	Low	Low	Low	Low

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 February 27, 1996.

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

Table 5
Total Particulate and Benzene Soluble Particulate Concentrations: Area Samples
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

Sampling Date	Area	Sampling Time (minutes)	Sample Volume (Liters)	Concentration (mg/m^3)	
				Total Particulate	Benzene Soluble Particulate
Conventional Asphalt Paving# **2/27/96†**	Screed Left (a)‡	431①	668①	0.29	0.15
	Screed Left (b)	430	860	4.2	4.0
	Screed Right (a)	431	862	2.4	2.2
	Screed Right (b)	382②	745②	1.3	1.1
	Highway Background (1)	520	1040	0.04	0.01
	Highway Background (2)	478	956	0.03	0.002
	Highway Background (3)	472	944	0.02	0.02
Conventional Asphalt Paving **2/29/96**	Screed Left (a)	500③	1000③	0.07	0.05
	Screed Left (b)	494	988	5.5	5.1
	Screed Right (a)	492	984	2.5	2.4
	Screed Right (b)	490	980	3.0	2.9
	Highway Background (1)	556	1112	0.01	ND (<0.02)
	Highway Background (2)	464④	626④	0.01	ND (<0.03)
	Highway Background (3)	474	948	0.01	ND (<0.02)
CRM Asphalt Paving **3/20/96†**	Screed Left (a)	541	1082	3.1	3.0
	Screed Left (b)	541	893	5.5	5.2
	Screed Right (a)	542	1084	4.0	4.0
	Screed Right (b)	542	1057	2.7	2.6
	Highway Background (1)	489	978	0.05	ND (<0.02)
	Highway Background (2)	464	928	0.03	ND (<0.02)
	Highway Background (3)	465	930	0.01	ND (<0.02)
CRM Asphalt Paving **3/21/96**	Screed Left (a)	466	932	6.3	6.1
	Screed Left (b)	469	915	3.8	3.5
	Screed Right (a)	470	940	5.3	5.3
	Screed Right (b)	469	938	2.8	2.6
	Highway Background (1)	423	846	0.02	ND (<0.02)
	Highway Background (2)	473	946	0.21	ND (<0.02)
	Highway Background (3)	464	928	0.02	ND (<0.02)

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.
① = At the end of the day the plastic cassette holding the sample filter was cracked. This lowered the post-calibration sampling flow rate to 1.1 Lpm. The overall sample volume and the concentrations for total particulate and benzene soluble particulate should be considered estimates.
② = Sampling pump faulted after 382 minutes. This time period was used to calculate the sample volume.
③ = At the end of the sampling period a crack was observed in the plastic cassette holding the sample filter. Since this could have affected the sample volume, the concentrations for total particulate and benzene soluble particulate should be considered estimates.
④ = A crack near the outlet of the plastic cassette holding the sample filter was observed at the end of the day. This lowered the post-calibration flow rate to 0.7 Lpm. The overall sample volume and the concentrations for total particulate and benzene soluble particulate should be considered estimates.
\# = The crew switched pavers and began traveling to a new site at 2:12 p.m. Samplers were turned off between 2:12 to 2:55 p.m. during this change-over.
† = Due to the cool weather in February, the CRM asphalt paving did not immediately follow the conventional asphalt paving.
‡ = 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).

Table 6
Respirable Particulate Concentrations: Area Samples
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

Sampling Date	Area	Sampling Time (minutes)	Sample Volume (Liters)	Concentration (mg/m^3)
Conventional AsphaltP 2/27/96†	Screed Left	432	734	0.98
	Screed Right	431	733	0.64
	Highway Background	520	884	ND (<0.02)
Conventional Asphalt 2/29/96	Screed Left	496	843	0.63
	Screed Right	492	836	1.4
	Highway Background	Sample Lost		
CRM Asphalt Paving 3/20/96†	Screed Left	541	920	1.4
	Screed Right	542	921	0.46
	Highway Background	489	831	0.04
CRM Asphalt Paving 3/21/96	Screed Left	469	797	1.8
	Screed Right	468	796	1.2
	Highway Background	441	750	ND (<0.03)

ND = Not Detected (below the Minimum Detectable Concentration)

mg/m^3 = Concentration, milligrams per cubic meter

= The crew switched pavers and began traveling to a new site at 2:12 p.m. Samplers were turned off between 2:12 to 2:55 p.m. during this change-over.

† = Due to the cool weather in February, the CRM asphalt paving did not immediately follow the conventional asphalt paving.

Table 7
Concentrations of Polycyclic Aromatic Compounds (PACs): Area Samples
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

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 PavingP **2/27/96†**	Screed Left (a)‡	431	862	129	19	133	ND (<0.35)
	Screed Left (b)	473	946	184	30	179	ND (<0.32)
	Screed Right (a)	431	862	126	43	224	ND (<0.35)
	Screed Right (b)	382	764	121	19	111	2.7
	Highway Background	520	1040	ND (<0.02)	ND (<0.02)	ND (<0.29)	ND (<0.29)
Conventional Asphalt Paving **2/29/96**	Screed Left (a)	493	986	280	80	258	ND (<0.30)
	Screed Left (b)	475	950	201	64	208	ND (<0.32)
	Screed Right (a)	497	994	140	22	110	1.1
	Screed Right (b)	437	874	186	19	228	1.5
	Highway Background	556	1084	ND (<0.02)	ND (<0.02)	ND (<0.28)	ND (<0.28)
CRM Asphalt Paving **3/20/96†**	Screed Left (a)	541	1082	585	108	313	21
	Screed Left (b)	541	1055	386	69	340	31
	Screed Right (a)	542	1084	174	30	246	51
	Screed Right (b)	544	1088	174	28	239	65
	Highway Background	489	978	ND (<0.03)	ND (<0.01)	ND (<0.6)	ND (<0.6)
CRM Asphalt Paving **3/21/96**	Screed Left (a)	469	938	639	113	739	28
	Screed Left (b)	468	913	622	108	389	39
	Screed Right (a)	472	944	259	39	373	83
	Screed Right (b)	470	917	158	23	195	65
	Highway Background	425	850	ND (<0.03)	ND (<0.01)	ND (<0.7)	ND (<0.7)

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)
# = The crew switched pavers and began traveling to a new site at 2:12 p.m. Samplers were turned off between 2:12 to 2:55 p.m. during this change-over.
† = Due to the cool weather in February, the CRM asphalt paving could not immediately follow the conventional asphalt paving.
‡ = 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: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

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 **2/27/96**	Screed Left	432	864	2289	1	2290	0.04%
	Screed Right	431	862	3323	3	3326	0.09%
	Highway Background	520	1014	8	0	8	n/a
Conventional Asphalt **2/29/96**	Screed Left	495	990	4480	1	4481	0.02%
	Screed Right	491	957	2702	0	2702	n/a
	Highway Background	556	1084	7	1	8	13%
CRM Asphalt Paving **3/20/96**	Screed Left	541	1055	4283	3	4286	0.07%
	Screed Right	542	1084	2755	0	2755	n/a
	Highway Background	489	978	2	2	4	50%
CRM Asphalt Paving **3/21/96**	Screed Left	466	932	8123	13	8136	0.16%
	Screed Right	467	934	2661	6	2667	0.22%
	Highway Background	424	848	7	7	14	50%

EC:TC = Ratio of Elemental Carbon to Total Carbon

n/a = Not applicable since one or both analytes were not detected

Other Comments:

Results have been rounded off to the nearest whole number

Table 9
Concentrations of Selected Volatile Organic Compounds (VOCs): Area Samples
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

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 2/27/96	Screed (left)	431	86	Trace	Trace	0.061	Trace	0.42	12
	Screed (right)	431	86	Trace	Trace	0.095	Trace	0.84	19
Conventional Asphalt Paving 2/29/96	Screed (left)	492	98	0.025	0.052	0.20	0.11	1.5	74
	Screed (right)	492	98	Trace	Trace	0.083	Trace	0.54	15
CRM Asphalt Paving 3/20/96	Screed (left)	541	108	0.055	0.13	0.61	0.49	2.9	111
	Screed (right)	542	108	0.019	0.050	0.23	0.19	1.2	34
CRM Asphat Paving 3/21/96	Screed (left)	469	94	0.40	0.12	0.50	0.12	2.7	106
	Screed (right)	470	94	0.021	0.050	0.22	0.18	1.2	36
Minimum Detectable Concentration		100 Liter air sample volume		0.006	0.010	0.009	0.024	0.03	0.04
Minimum Quantifiable Concentration		100 Liter air sample volume		0.018	0.031	0.027	0.072	0.1	0.12

mg/m^3 = Concentration, expressed in milligrams per cubic meter.

† = Total hydrocarbons with a gas chromatograph retention time less than (<) toluene. These concentrations are expressed in milligrams per cubic meter (mg/m^3) and have been quantified as n-hexane.

‡ = Total hydrocarbons with a gas chromatograph retention time greater than (>) toluene. These concentrations are expressed in milligrams per cubic meter (mg/m^3) and have been quantified as Stoddard Solvent.

MIBK = Methyl isobutyl ketone.

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

Table 10
Total Particulate and Benzene Soluble Particulate Concentrations: Personal Breathing-Zone Samples
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

Sampling Date	Activity	Sampling Time (minutes)	Sample Volume (Liters)	Concentration (mg/m^3)	
				Total Particulate	Benzene Soluble Particulate
Conventional Asphalt PavingP **2/27/96‡**	Paver Operator	479	958	0.64	0.42
	Screed Operator	286①	558①	0.40	0.23
	Truck Dumper	440	880	0.29	0.23
	Traffic Control	443	886	0.21	0.12
	Breakdown Roller Operator	483	966	0.04	0.04
	Intermediate Roller Operator†	418	836	0.17	0.06
	Rumble Strip Roller Operator†	356	712	0.05	0.01
	Crew Foreman†	449	898	0.22	0.03
Conventional Asphalt Paving **2/29/96**	Paver Operator	497	994	1.03	0.82
	Screed Operator	494	988	0.47	0.37
	Truck Dumper	478	932	0.68	0.49
	Traffic Control	491	982	0.46	0.35
	Breakdown Roller Operator	488	976	0.06	(ND)
	Rumble Strip Roller Operator†	489	978	0.02	(ND)
CRM Asphalt Paving‡ **3/20/96**	Paver Operator	524②	996	0.11	(ND)
	Screed Operator	552	1049	0.15	0.01
	Truck Dumper	544	1061	0.60	0.30
	Traffic Control	521	1016	0.17	0.06
	Breakdown Roller Operator	509	1018	0.08	ND
	Intermediate Roller Operator†	457	891	0.03✦	0.74✦
	Rumble Strip Roller Operator†	507	989	0.08	0.02
CRM Asphalt Paving **3/21/96**	Paver Operator	482	940	0.17	0.06
	Screed Operator	488	952	0.26	0.09
	Truck Dumper	490	956	0.36	0.18
	Traffic Control	487	974	0.15	0.05
	Breakdown Roller Operator	494	963	0.10	(ND)
	Intermediate Roller Operator†	494	963	0.04	(ND)

mg/m^3 = Concentration, milligrams per cubic meter
† = These activities were not sampled on all four days.
‡ = Due to cool weather, the CRM asphalt paving could not begin immediately following the conventional asphalt paving.
# = The crew switched pavers and began traveling to a new site at 2:12 p.m. Sampling pumps were turned off between 2:12 to 2:55 p.m. during this change-over.
① = Sampling pump faulted prior to collecting a full-shift sample. Sample volume calculated for period that the sampling pump operated.
② = The Tygon™ tubing connecting the sample filter to the sample pump was reconnected at 12:00 p.m.
✦ = Concentrations should be considered suspect since the benzene soluble particulate fraction concentration exceeded the total particulate concentration.
ND = Not Detected (below the Minimum Detectable Concentration).
(ND) = After blank correction some benzene soluble fraction samples had a negative weight which are denoted using (ND).

Table 11
Concentrations of Polycyclic Aromatic Compounds (PACs): Personal Breathing-Zone Samples
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

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 PavingP 2/27/96†	Paver Operator	479	958	18	2.8	ND (<0.31)	ND (<0.31)
	Screed Operator	286①	572	3.6	0.49	ND (<0.52)	ND (<0.52)
	Truck Dumper	440	880	12	1.9	ND (<0.34)	ND (<0.34)
	Traffic Control	368	736	6.5	1.0	ND (<0.41)	ND (<0.41)
	Breakdown Roller Operator	483	966	0.29	Trace	ND (<0.31)	ND (<0.31)
	Intermediate Roller Op.✦	210②	420	1.2	Trace	ND (<0.71)	ND (<0.71)
	Rumble Strip Roller Op.✦	356	712	0.20	Trace	ND (<0.42)	ND (<0.42)
	Foreman✦	449	898	1.4	0.20	ND (<0.33)	ND (<0.33)
Conventional Asphalt Paving 2/29/96	Paver Operator	497	994	49	6.5	35	1.0
	Screed Operator	448	896	23	3.5	8.3	ND (<0.33)
	Truck Dumper	478	932	20	2.7	11	ND (<0.32)
	Traffic Control	491	982	14	2.1	3.5	ND (<0.31)
	Breakdown Roller Operator	488	976	0.18	Trace	ND (<0.31)	ND (<0.31)
	Rumble Strip Roller Op.	489	978	ND (<0.02)	ND (<0.02)	ND (<0.31)	ND (<0.31)
CRM Asphalt Paving 3/20/96†	Paver Operator	524	1022	5.7	0.82	5.0	12
	Screed Operator	552	1076	7.0	0.93	6.9	11
	Truck Dumper	544	1061	30	4.6	42	44
	Traffic Control	521	1042	11	1.6	18	22
	Breakdown Roller Operator	509	993	0.99	0.12	ND (<0.6)	4.2
	Intermediate Roller Operator†	457	823	0.73	0.10	ND (<0.7)	Trace
	Rumble Strip Roller	507	989	1.6	0.20	ND (<0.6)	Trace
CRM Asphalt Paving 3/21/96	Paver Operator	482	940	12	1.7	10	24
	Screed Operator	488	976	10	1.3	9.5	20
	Truck Dumper	490	980	28	4.2	35	43
	Traffic Control	487	938	9.1	1.2	8.1	18
	Breakdown Roller Operator	495	963	0.77	0.10	ND (<0.6)	3.7
	Intermediate Roller Op.	494	988	Trace	Trace	ND (<0.6)	Trace

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)
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.
① = Sampling pump faulted and ran only 10 minutes after worker moved to the new paving site.
② = Sampling pump faulted and restarted during work day.
= The crew switched pavers and began traveling to a new site at 2:12 p.m. Samplers were turned off between 2:12 to 2:55 p.m. during this change-over.
† = Due to the cool weather in February, the CRM asphalt paving could not immediately follow the conventional asphalt paving.
✦ = These work activities were not sampled for all four days of the survey.
• = The PACs concentrations reported in this table include both the particulate phase (collected on the filter) and the vapor phase (from the sorbent tube).

Table 12
Number of Acute Symptom Questionnaires Completed by Workers
Paving Company: Staker Paving, Casa Grande, Arizona (HETA 96-0072)

Work Group ‡		Acute Questionnaires Completed			
		2/27/96 Day 1 Conventional Asphalt	2/29/96 Day 2 Conventional Asphalt	3/20/96 Day 3 CRM Rubber Asphalt	3/21/96 Day 4 CRM Rubber Asphalt
Pavers (n=6)		30/30	30/30	30/30	30/30
Non-pavers (n=6)		29/20	26/30	28/30	30/30
Paving Period Totals	Pavers	60/60		60/60	
	Non-pavers	55/60		58/60	

‡ = All six pavers and six non-pavers participated in the study for all four survey days.

Table 13
Number of Workers Reporting Symptoms and Number of Symptom Occurrences by Survey Day
Paving Company: Staker Paving, Casa Grande, Arizona (HETA 96-0072)

Symptoms	Work Groups‡	Number of workers reporting symptoms (Number of symptom occurrences reported)			
		2/27/96 Day 1 Conventional Asphalt	2/29/96 Day 2 Conventional Asphalt	3/20/96 Day 3 CRM Asphalt	3/21/96 Day 4 CRM Asphalt
Dry, itching, or irritated eyes	Pavers	1(2)	2 (5)	1 (1)	1 (4)
	Non-pavers	0	1 (1)	0	0
Stuffy, burning, or irritated nose	Pavers	2 (3)	3 (11)	2 (6)	3 (10)
	Non-pavers	1 (3)	2 (5)	2 (3)	1 (1)
Sore, dry, scratchy, or irritated throat	Pavers	1 (2)	1 (4)	1 (4)	2 (7)
	Non-pavers	0	1 (4)	0	0
Skin burning, rash, itching, or irritated	Pavers	1 (4)	1 (2)	1 (2)	0
	Non-pavers	0	0	0	0
Bothered by coughing	Pavers	0	1 (4)	1 (4)	1 (3)
	Non-pavers	1 (5)	1 (1)	0	0
Chest tightness or shortness of breath	Pavers	0	0	0	0
	Non-pavers	0	0	0	0
Wheezing or whistling in chest	Pavers	0	0	0	0
	Non-pavers	0	0	0	0
Totals	Pavers (n=6)	3 (11)	4 (26)	4 (17)	3 (24)
	Non-pavers (n=6)	2 (8)	3 (11)	2 (3)	1 (1)

‡ = All six pavers and six non-pavers participated in the study for all four survey days.

Table 14
Rate of Symptoms Occurrence Per Questionnaire Among Pavers by Survey Day
Paving Company: Staker Paving, Casa Grande, Arizona (HETA 96-0072)

Pavers‡ (n=6)	**2/27/96 Day 1 Conventional Asphalt**	**2/29/96 Day 2 Conventional Asphalt**	**3/20/9 Day 3 CRM Rubber Asphalt**	**3/21/96 Day 4 CRM Rubber Asphalt**
Completed Questionnaires	30	30	30	30
Symptom Occurrences	11	26	17	24
Rate of symptom occurrence per questionnaire	0.37	0.87	0.57	0.80
	0.62P		0.68‡	

‡ = All six pavers and six non-pavers participated in the study for all four survey days.
P = Average rate (over two days) of symptom occurrence per questionnaire

Table 15
Estimated Hours of Exposure to Asphalt Fume Among Pavers by Job Title and Survey Day
Paving Company: Staker Paving, Casa Grande, Arizona (HETA 96-0072)

Job Title (n= 6)‡	**Estimated hours exposure to asphalt fume**			
	2/27/96 Day 1 Conventional Asphalt	**2/29/96 Day 2 Conventional Asphalt**	**3/20/96 Day 3 CRM Rubber Asphalt**	**3/21/96 Day 4 CRM Rubber Asphalt**
Paver Operator	6.25	7.0	8.5	8.0
Screed Operator	7.0	7.25	8.75	8.0
Dump Person	7.25	7.5	8.75	8.0
Traffic Control / Flagger	7.0	8.25	8.5	7.75
Roller Operator #2	6.75	8.5	8.75	7.75
Breakdown Roller #1	7.25	7.0	8.5	7.75
Daily Total Hours (Average)	41.5 (6.9)	45.5 (7.6)	51.75 (8.6)	47.25 (7.9)
Total Hours by Asphalt Type (Average)	87 (7.25)		99 (8.25)	

‡ = All six pavers and six non-pavers participated in the study for all four survey days.

Table 16
Rate of Symptoms Per Hour of Exposure Among Pavers by Survey Day
Paving Company: Staker Paving, Casa Grande, Arizona (HETA 96-0072)

Pavers (n=6)‡	**2/27/96 Day 1 Conventional Asphalt**	**2/29/96 Day 2 Conventional Asphalt**	**3/20/96 Day 3 CRM Rubber Asphalt**	**3/21/96 Day 4 CRM Rubber Asphalt**
Estimated Exposure to Asphalt (total hours)	41.5	45.5	51.75	47.25
Number Symptom Occurrences	11	26	17	24
Rate (symptom occurrence/hr exposure)	0.27	0.57	0.33	0.51
	0.43P		0.41P	

‡ = All six pavers and six non-pavers participated in the study for all four survey days.
P = Average rate (over two days) of symptom occurrences per hour of paving exposure.

Table 17
Summary of Area Concentrations of Air Contaminants
Paving Site: Staker Construction Company, Casa Grande, Arizona (HETA 96-0072)

	Analyte	TWA Concentration, expressed in micrograms per cubic meter							
		2/27/96 Conventional		2/29/96 Conventional		3/20/96 CRM Asphalt		3/21/96 CRM Asphalt	
Air Sample Position at Screed ➜		Left	Right	Left	Right	Left	Right	Left	Right
Paver Screed	Total Particulate	290	2400	70	2500	3100	4000	6300	5300
	Benzene Soluble Fraction	150	2200	50	2400	3000	4000	6100	5300
	Total Particulate	4200	1300	5500	3000	5500	2700	3800	2800
	Benzene Soluble Fraction	4000	1100	5100	2900	5200	2600	3500	2600
	PACs$_{370}$ (vapor & particulate)	129	126	280	140	585	174	639	259
	PACs$_{400}$ (vapor & particulate)	19	43	80	186	108	30	113	39
	PACs$_{370}$ (vapor & particulate)	184	121	201	22	386	174	622	158
	PACs$_{400}$ (vapor & particulate)	30	19	64	19	69	28	108	23
	Benzothiazole	ND (<0.35)	ND (<0.35)	ND (<0.3)	1.1	21	51	28	83
	Other Sulfur Compounds	133	224	258	110	313	246	739	373
	Benzothiazole	ND (<0.32)	2.7	ND (<0.32)	1.5	31	65	39	65
	Other Sulfur Compounds	179	111	208	228	340	239	389	195
	Total Hydrocarbons with a retention time < toluene	420	840	1500	540	2900	1200	2700	1200
	Total Hydrocarbons with a retention time > toluene	12000	19000	74000	15000	111000	34000	106000	36000
	Respirable Particulate	980	640	630	1400	1400	460	1800	1200
Highway Backgnd.	Total Particulate‡	30		10		30		80†	
	Benzene Soluble Fraction‡	10		ND (<20)		ND (<20)		ND (<20)	
	PACs$_{370}$ (vapor & particulate)	ND (<0.02)		ND (<0.02)		ND (<0.03)		ND (<0.03)	
	PACs$_{400}$ (vapor & particulate)	ND (<0.02)		ND (<0.02)		ND (<0.01)		ND (<0.01)	
	Benzothiazole	ND (<0.29)		ND (<0.28)		ND (<0.6)		ND (<0.7)	
	Other Sulfur Compounds	ND (<0.29)		ND (<0.28)		ND (<0.6)		ND (<0.7)	
	Respirable Particulate	ND (<20)		Sample Lost		40		ND (<30)	

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
† = The samples collected on 3/21/96 ranged from 20 to 210 µg/m^3.