HETA 94-0219-2620
Walsh Construction Company
Boston, Massachusetts

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Preface

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Acknowledgments and Availability of Report

This report was prepared by David C. Sylvain and Aubrey K. Miller, of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by James Allen, M.D., Veronica Herrera, M.D., and Beth Reh. Desktop publishing by Pat Lovell.

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Health Hazard Evaluation Report 94-0219-2620
Walsh Construction Company
Boston, Massachusetts
January 1997

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SUMMARY

On December 8-9, 1995, NIOSH investigators conducted industrial hygiene and medical assessments on two separate paving crews (crew #1 and crew #2) working within the Third Harbor Tunnel (Ted Williams Tunnel) in Boston, Massachusetts. The evaluation took place during a single overnight work-shift (approximately 3:00 p.m. - 4:00 a.m.). 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.

The highest concentrations of total particulate (TP), benzene soluble fraction (BSF), and polycyclic aromatic compounds (PACs) were measured above the paver screed auger. Concentrations of TP, BSF, and PACs in area samples varied between sampling locations and between the two paving crews. None of the PBZ exposures to asphalt fume exceeded the ACGIH TLV of 5 mg/m^3 as an 8-hour TWA. In every PAC sample, low-molecular-weight PACs exceeded high-molecular-weight PACs. Personal and area sampling found that both crews were exposed to similar TP and BSF concentrations. Area sampling for PACs found slightly higher concentrations at the crew #1 paver seat. Measured area TP, BSF, and PAC concentrations were up to ten times higher than those found during recent NIOSH investigations of open-air paving, indicating poor ventilation within the tunnel.

The five workers on crew #1 reported 38 acute health symptoms in association with their work exposures during the survey. However, no acute health symptoms were reported by the four workers on crew #2 during the survey. The most frequently reported symptoms in association with the work exposures were eye irritation, cough, nasal irritation, and shortness of breath. Eighty-four percent of the reported symptoms were rated as "mild" in severity from choices of "mild," "moderate," or "severe."

Peak expiratory flow rate (PEFR) measurements revealed three workers (one from crew #1 and two from crew #2) with significant bronchial lability (i.e., difference between the minimum and the maximum PEFR exceeded 20% of the day's maximum PEFR) during the survey. Only one of these workers reported any acute respiratory symptoms concurrent with bronchoreactivity. Only one (non-symptomatic worker) of the three workers with bronchoreactivity had a history of smoking. While pulmonary function abnormalities from exposure to asphalt fumes have not previously been reported in the medical literature, this finding is suggestive of a potential occupational association between road paving work and pulmonary abnormalities. Data from this evaluation, however, are based on a very small, and possibly unrepresentative, sample of pavers and reflect production and environmental conditions specific to this site.

Although measured area TP, BSF, and PAC concentrations were up to ten times higher than those found during recent NIOSH investigations of open-air paving, personal breathing zone exposures to asphalt fume did not exceed the ACGIH TLV. It is possible, however, that some pavers may have been exposed to total particulate concentrations which exceeded the 15-minute ceiling established by NIOSH as a REL. Concentrations of low-molecular-weight PACs exceeded those of high molecular weight PACs, implying that the 2-3 ring PACs, felt to be more responsible for irritant effects, may have been more abundant.

The most frequently reported symptoms in association with the work exposures were eye irritation, cough, nasal irritation, and shortness of breath. The notably higher concentrations of TP, BSF, and PACs measured at this site, as compared to open-air paving sites, may have been responsible for significant bronchial lability observed in three workers.

Keywords: SIC 1611 (Highway and Street Construction), asphalt fume, benzene soluble particulate, bitumen, elemental carbon, eye irritation, highway tunnel, PACs, paving, polycyclic aromatic compounds, respiratory irritation.

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INTRODUCTION

In March 1994, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from representatives of Walsh Construction Company concerning a variety of worker exposures and activities during construction of the Boston Third Harbor Tunnel (Ted Williams Tunnel) in Boston, Massachusetts. Based on follow-up phone conversations with Walsh representatives; NIOSH investigators decided that the HHE would focus on exposures and potential health effects associated with asphalt paving.

On October 2, 1995, an initial site visit, which included a discussion of anticipated paving operations and a walk-through inspection of the tunnel, was conducted. On December 8-9, 1995, NIOSH investigators conducted industrial hygiene and medical assessments on two paving crews working within the Third Harbor Tunnel. The evaluation took place during a single overnight work-shift (approximately 3:00 p.m. - 4:00 a.m.). 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. All participants were notified of their individual lung function test results by letter in June 1996.

BACKGROUND

Process Overview

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

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

- 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.
- 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.
- 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.

- 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 paver operator who drives the paver; one or two screed operators who control and monitor the depth and width of the HMA placement; one or two rakers who shovel excess HMA, fill in voids and prepare joints; laborers who perform miscellaneous tasks; roller operators who drive the rollers; and a tackman who applies the tackcoat. The paver operators and roller operators do not usually perform different jobs, while the screed operators, rakers, and laborers may perform a variety of tasks throughout the workday.

Site Description

The 8300-foot-long Third Harbor Tunnel which extends beneath Boston Harbor between Boston and East Boston, is reported to be one of the longest underwater highway tunnels in the United States. The central portion of the tunnel, which is located beneath the harbor, is constructed of 12 immersed tube-sections which were floated into place, and then submerged in an underwater excavation that was dredged along the harbor floor. The binocular-like tube sections are lined with concrete and are joined end-to-end to create two parallel tunnels, each of which is approximately 40 feet wide and encloses two traffic lanes. At the ends of the tubes, the roadway widens as it surfaces and merges into additional highway lanes.

During the investigation, crews paved the entire immersed tube (approximately one mile long), and a portion of the wider east end. HMA was applied by two paving crews, working simultaneously, proceeding from west to east (Boston to East Boston). The paving crews applied two distinct layers of HMA (binder and finish coats) over the same road surface. Initially, a 2½-inch layer of HMA (binder coat) was laid down over a tack coat which had been applied to the concrete surface earlier in the day. After application of the binder coat, the paving crews returned to the starting point, and applied a 2-inch layer of HMA (finish coat).

The HMA was supplied by a plant located several miles from the tunnel. Both mixes were furnished according to formulas specified by the Massachusetts Department of Public Works. The nominal size of coarse aggregate components was 3/8 to 1½ inches. The fine aggregate blend consisted of 75% screenings and 25% stone sand. The asphalt was grade AC-10, to which 1% “Ad-here” anti-strip additive had been added to promote adhesion and reduce stripping. Additionally, a very small amount of silicone fluid (one ounce per 5000 gallons of asphalt cement) was added to the asphalt cement. The silicone is typically added to decrease asphalt foaming and improve asphalt cement workability. Asphalt was delivered in Flow-Boy semi-trailers and 10-wheel dump trucks, which, after entering via the east end of the tunnel, backed through the tunnel to the paving site.

The two paving crews were typically located several hundred feet apart. Each crew included approximately ten workers: one paver operator, two screedmen, and approximately seven rakers/laborers. Each crew applied pavement using a Barber-Green BG 265 paver at a rate of 80 to 100 feet per minute and at a temperature of 310°F. The two pavers were followed by five rollers (four Dresser, one Ingersol-Rand). All equipment and trucks used in the tunnel were diesel-powered. The only vehicular traffic present during the survey was associated with the paving operations.

During paving, ventilation was provided by reversible air handling units located at the east end of the tunnel. Although the units could move air in either direction through the tunnel, a west to east airflow (Boston to East Boston) was maintained throughout the survey. The permanent tunnel ventilation system was not fully operational at the time of the evaluation. This system is designed to remove vehicle exhaust when the tunnel is open to traffic.

METHODS

Industrial Hygiene

Asphalt fume exposures have typically been measured as total particulates (TP) and the benzene-soluble particulate fraction (BSF) of the particulates. However, since neither of these 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 road dust will contribute to total particulate levels. In an effort to address this situation, 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.

The industrial hygiene evaluation consisted of observation of work practices [(including the use of personal protective equipment (PPE)] and environmental sampling during paving operations. Except for samples obtained using direct-reading stain-length methods, 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). Calibration of the air sampling pumps with the appropriate sampling media was performed before and after the monitoring period. Field blanks were collected and submitted to the laboratory for each analytical method.

Area Air Sampling

To evaluate worst-case conditions and characterize the asphalt fume, an area air sample was collected above the screed auger of paver #1. Additional area samples ("seat samples") were collected at the operator's seat on each paver and one roller with crew #1. Area samples were collected for total particulate, benzene soluble fraction, PACs, and elemental and organic carbon. Stain-length diffusion tubes were also attached to the equipment seats to evaluate carbon monoxide and nitrogen dioxide.

Personal Air Sampling

NIOSH investigators had planned to collect air samples for all workers on a single crew, including those such as roller operators who had been found in previous NIOSH studies to have less potential for asphalt fume exposure.[24,25,26] The unexpected use of two paving crews on the survey day provided an opportunity to modify the sampling strategy to preferentially evaluate those workers in closest proximity to each of the two pavers (presumably the highest asphalt fume exposures). Ten workers (five from each crew) were selected for personal breathing-zone monitoring. Workers monitored on crew #1 included the paver operator, one screedman, one raker, one laborer, and one roller operator. Workers monitored on crew #2 included the paver operator, three rakers, and one laborer. Personal air samples were analyzed for total particulate and the benzene-soluble fraction.

Total Particulate/Benzene Soluble Fraction (BSF)

Each sample was collected on a tared 37-millimeter diameter, 2-micrometer (µm) pore-size Zefluor® polytetrafluoroethylene (PTFE) filter mounted in a closed-face cassette. Samples were collected at a nominal flow rate of 2.0 liters per minute (lpm). Gravimetric analysis for total particulate weight was conducted according to NIOSH Method 0500[27] with the following modifications: 1) the filters and backup pads were stored in an environmentally controlled room (21±3°C, 50±5% relative humidity), and were subjected to room conditions for at least two hours prior to tare and gross weighings; 2) two gross and tare weighings were performed to obtain averages; 3) filters were placed on antistatic radiation pads prior to tare and gross weighings. The total weight of each sample was determined by weighing the sample plus the filter on an electrobalance and subtracting the previously determined tare weight. Sample values less than the limit of detection (LOD) were reported as not detected (nd). The LOD was 0.01 milligrams (mg) per sample.

Samples were analyzed for benzene-solubles according to the OSHA 58 method, with the following modifications: 1) samples were not transferred to scintillation vials before shipment; 2) Gelman Acrodisc CR were used instead of 13mm stainless steel filters; 3) samples were collected on Zefluor® filters rather than glass fiber filters.

Polycyclic Aromatic Compounds (PACs)

The sampling train consisted of 37-mm, 2µm pore size, Zefluor® filter to collect particulate PACs, connected in series with an ORBO 42 sorbent tube to collect volatile or semi-volatile PACs. Samples were collected at a nominal flow rate of 2.0 lpm.

The collected 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 was retained on the column, and the aliphatic and the aromatic compounds were eluted with hexane. Polar compounds were eluted from the column with methanol. Dimethyl sulfoxide (DMSO) was added to the hexane solution to partition the aromatic compounds into the DMSO layer, while the aliphatic compounds remain in the hexane layer. The aromatic compounds in the DMSO fraction were 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.

Elemental Carbon (EC) and Organic Carbon (OC)

Elemental carbon was measured to determine if diesel exhaust could have contributed to the air contaminants measured at the paving site. Each sample was collected on a 37-millimeter-diameter quartz fiber filter mounted in an open-face cassette at a nominal flow rate of 2.0 lpm. Samples were analyzed using the thermal-optical method, in which various carbon types (organic, carbonate, and elemental) are speciated through temperature and atmosphere control, and continuous monitoring of filter transmittance (draft NIOSH Method 5040)[27]. Additional information on the design and operation of the thermo-optical analyzer is presented in Appendix A.

Carbon Monoxide and Nitrogen Dioxide

Direct-reading diffusion detector tubes were used to measure time-weighted-average (TWA) concentrations. The calibration and use of stain-length diffusion tubes is based upon Fick's First Law of Diffusion.[1] The tubes have a calibrated scale which is used to read the length of stain as ppm x hours. The range of measurement for an 8-hour sampling period was 6.3 - 75 ppm for carbon monoxide, and 1.3 - 25 ppm for nitrogen dioxide.[1]

Medical

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

All pavers on both work crews (approximately 20 workers) were asked to participate in the study.

Nine pavers (5 pavers from crew #1 and 4 pavers from crew #2) subsequently volunteered and were included in the health assessment. A short questionnaire concerning the recent occurrence of symptoms, ongoing respiratory conditions, work history, and smoking habits was privately administered to study participants. In addition to the questionnaire, acute symptom surveys were administered five times (approximately every two hours) to all study participants during their work-shift to determine if eye, nose, throat, skin, or respiratory symptoms (including cough, chest tightness, or wheezing) were occurring in association with their job tasks.

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

EVALUATION CRITERIA

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

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs)[2], (2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs™)[3] and (3) the U.S. Department of Labor, OSHA Permissible Exposure Limits (PELs)[4]. 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 which were originally promulgated in 1971. However, some states with OSHA-approved state plans continue to enforce the more protective limits promulgated in 1989. For exposures with evaluation criteria, NIOSH encourages employers to use the 1989 OSHA PEL or the NIOSH REL, whichever is lower.

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

It is important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these occupational health exposure criteria. A small percentage may experience adverse health effects because of individual susceptibility, preexisting medical conditions, previous exposures, or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, or with medications or personal habits of the worker (such as smoking) to produce health effects even if the occupational exposures are controlled to the limit set by the evaluation criterion. These combined effects are often not considered by the chemical-specific evaluation criteria. Furthermore, many substances are appreciably absorbed by direct contact with the skin and thus potentially increase the overall exposure and biologic response beyond that expected from inhalation alone. Finally, evaluation criteria may change over time as new information on the toxic effects of an agent become available. Because of these reasons, it is prudent for an employer to maintain worker exposures well below established occupational health criteria.

Asphalt Fumes (Petroleum)

Asphalt, produced from refining crude petroleum, is commercially valuable for pavement construction because of its adhesive properties, flexibility, durability, water and acid resistance, and its ability to form strong cohesive mixtures with mineral aggregates. Asphalt pavement is the major paving product in commercial use and accounts for 85% of the total asphalt usage (and over 90% of the roadway paving) in the United States.[5] About 4,000 HMA facilities and 7,000 paving contractors employ nearly 300,000 workers in the United States.[5]

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.[5]

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.[6] 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.[7] Coal tar has a greater reported carcinogenic activity than asphalt and is considered an occupational carcinogen by NIOSH and ACGIH.[2,3]

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 total particulate. 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.[8] Asphalt fumes can be absorbed through the lungs or the skin. Hansen[9] and Maizlish et al.[10] 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.[11] 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 NIOSH criteria document, 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.[12] This recommendation was based on information presented in the 1977 criteria document and a study by Niemeier et al.[7] 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.[9,10,13,14,15,16,17,18,19,20]

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 (total particulate) for general industry as well as for the maritime, construction, and agricultural industries.[21] OSHA is presently reviewing public comments. The current ACGIH TLV® for asphalt fumes is 5 mg/m^3 as an 8-hour TWA.[3] This TLV was recommended to "maintain good housekeeping conditions and reduce the risk of possible carcinogenicity."[22]

Table 1 summarizes the toxicity and exposure criteria information for asphalt fume and the other contaminants evaluated during this study, including total particulate, benzene soluble particulate fraction, PACs, elemental carbon, carbon monoxide, and nitrogen dioxide.

RESULTS

Industrial Hygiene

Total Particulate (TP) / Benzene Soluble Fraction (BSF)

The results of personal air sampling for total particulate (TP) and benzene soluble fractions (BSF) are presented in Table 2a (note: the sampling cassette worn by the paver operator on crew #2 was not analyzed due to problems with retrieval at the end of the survey). Concentrations of total particulate and BSF in PBZ samples ranged from 1.09 to 2.17 mg/m^3, and 0.30 to 1.26 $\mu g/m^3$, respectively. The highest PBZ TP concentrations were in samples collected from two rakers working on crew #2, followed by the roller and paver operators from crew #1. The highest PBZ BSF concentrations were in samples from the same two rakers working on crew #2, followed by the paver operator and a raker from crew #1. The BSF comprised 41 to 60 percent of the total mass of the personal samples.

The results of area air sampling for TP and BSF are presented in Table 2b. As expected, the highest concentrations of TP were measured in samples collected above the paver screed auger (13.1 mg/m^3, TWA) and the BSF comprised approximately 95 percent of TP. Crew #1 seat samples for TP measured 0.84 mg/m^3 at the paver, and 0.44 mg/m^3 at the roller; with the BSF comprising 50 % and 21% of these samples respectively. The paver #2 seat sample for TP measured 4.43 mg/m^3 and the BSF comprised 77% of this sample.

Polycyclic Aromatic Compounds (PACs)

Table 3 summarizes the total PAC concentrations in area samples collected at equipment seats (crew #1 paver and roller; crew #2 paver) and the screed auger (crew #1 paver). The values reported in Table 3 are indicators of low- and high-molecular-weight compounds; however, these values are *not* additive. The area sample collected in the plume at the #1 paver screed auger revealed concentrations of 355 and 95 $\mu g/m^3$ for low- and high-molecular-weight compounds, respectively. The concentration of low-molecular-weight PACs measured in seat samples ranged from 20.2 (#1 roller) to 62 $\mu g/m^3$ (#1 paver), while the concentrations of high-molecular-weight PACs in seat samples ranged from 4.9 (#1 roller) to 13.3 $\mu g/m^3$ (#1 paver). In every sample, measured concentrations of low molecular weight PACs exceeded those of high molecular weight PACs, implying that the 2-3 ring PACs may be more abundant.

Elemental Carbon (EC) and Organic Carbon (OC)

The results of air sampling for elemental and organic carbon are presented in Table 4. The sample collected at the screed auger was very heavily loaded. The analyst estimated that the reported results represent approximately 70 percent of OC actually collected on the filter, in which case the actual OC concentration would have been approximately 5400 $\mu g/m^3$. In general, a higher elemental carbon (EC) to total carbon (TC) ratio suggests that diesel engine exhaust may be contributing to other exposure measurements (such as the PAC results). The EC:TC ratio during this survey ranged from 0.013 to 0.042. A previous NIOSH study reported that EC in diesel exhaust comprises 60 to 80 percent of total carbon, which implies that diesel exhaust did not contribute significantly to exposure measurements during the present evaluation.[23]

Carbon Monoxide and Nitrogen Dioxide

An indistinct color change *may* have occurred in two carbon monoxide (CO) tubes. No color change was evident on any of the other tubes. The minimum 8-hour TWA concentration that could be quantified using these tubes was 6.3 ppm. No nitrogen dioxide was detected.

Medical

Nine pavers, 45% of the two paving crews, participated in the health assessment. These workers typically worked on road paving crews an average of 55 hours per week for 40 weeks per year. Eight of the nine pavers (89%) were male. Pavers on crew #1 (average age 33 years; range 27-41 years) were younger than crew #2 (average age 51 years; range 47-55 years). Correspondingly, the average number of years a worker had been employed at their current job title was lower for crew #1(8 years) than for crew #2 (18 years). The five pavers from crew #1 included one paver operator, one screed operator, one roller operator, one raker, and one laborer. The four pavers from crew #2 included one paver operator, two rakers, and one laborer. Four of the pavers currently smoked cigarettes (three smoked during work), one was a former smoker, and four never smoked. The four workers who currently smoked cigarettes were divided evenly between the two paving crews.

During the work-shift, five acute symptom surveys were administered at approximately two-hour intervals to each worker. Thus, 45 (nine workers times five surveys) acute symptom surveys were completed. Responses to the surveys 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 reported all seven symptoms during each survey, he/she would have 35 symptom occurrences for the day.

The five workers on paving crew #1 reported 38 symptom occurrences (each worker reported at least one symptom occurrence) over the work-shift. No symptom occurrences were reported by the four workers on paving crew #2. The most frequently reported symptoms among paving crew #1 workers were eye irritation (32%); cough (21%); nasal irritation (21%); and shortness of breath (16%). Eighty-four percent (32/38) of the symptoms reported by the pavers were rated as "mild" in severity, from choices of "mild," "moderate," or "severe."

At the time of the survey, all nine workers denied the presence of ongoing colds or other illness. Additionally, all the workers' medical histories were negative with respect to allergies, asthma, recurrent pulmonary infections, and bronchitis. Seven of the nine pavers completed a short questionnaire concerning the occurrence of symptoms during the week prior to the NIOSH survey. Three workers (two from crew #1 and one from crew #2) reported having symptoms associated with their workactivities during this time. One worker reported headaches, one worker reported eye irritation, and the remaining worker reported eye, nose, and throat irritation.

Three workers (one from crew #1 and two from crew #2) demonstrated PEFR changes 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). Only one of these workers reported any acute respiratory symptoms concurrent with bronchoreactivity. Two of these workers never smoked cigarettes (one of which reported symptoms) and one was a current smoker.

DISCUSSION

Industrial Hygiene

The most significant difference between this site and other paving sites evaluated by NIOSH was its location within a tunnel. Although mechanical ventilation pulled air into the west end of the tunnel, air movement and air temperature were highly variable throughout the sampling period. Temperature and air velocity measurements made at 10:44 p.m. near the point where the tunnel widened at the east end indicated 41°F, 17% relative humidity, and an airflow of approximately 700 feet per minute (fpm). Eleven minutes later, the temperature had decreased to 34°F, with a relative humidity of 13%, and airflow of 700 fpm. No temperature or air velocity measurements were made in the middle of the tunnel (in the immersed tube) where air movement seemed negligible and it felt considerably warmer (workers removed jackets and worked in short-sleeves). Measured area TP, BSF, and PAC concentrations were up to ten times higher than those found during recent NIOSH investigations of open-air paving,[24-26] indicating poor ventilation within the tunnel.

Highest concentrations of TP, BSF, and PACs were measured in the plume above the paver screed auger. Also, the BSF:TP ratio was highest in area samples collected directly over the screed auger. It is not clear whether the difference between the BSF:TP ratio at the screed versus the personal samples (and seat samples) indicates that BSF concentrations decrease over time and/or distance, or if the ratio is an artifact of the analytical method. On an open-air site, TP from road dust, or the operation of equipment such as front-end loaders could result in a lower BSF:TP ratio; however, this site, "isolated" in the tunnel, was characterized by the absence of road dust and other sources of TP aside from paving.

The TP concentration measured at the #2 paver seat (4.43 mg/m^3) was more than five times the TP concentration at the #1 paver seat (0.84 mg/m^3). The dissimilarity between these results may be due to differences between the location of the cassettes on each of the pavers. Since the two pavers were laying-down the same HMA under the same conditions (e.g., formulation, temperature, thickness, rate of application), it seems that much (if not most) of the variability between samples collected on the pavers would result from differences in the location of the samplers, especially in relation to the plume above the screed auger. Interestingly, TP and BSF concentrations measured at the #2 paver seat were higher than at the #1 paver seat, while the PACs (low and high molecular weight) were higher at the #1 paver seat than at the #2 paver seat. Again, this may be explained, at least in part, by the position of the sampling cassettes on each paver.

The TP concentrations measured at crew #1 paver and roller operators' seats (0.84 mg/m^3 and 0.44 mg/m^3, respectively) were much lower than the concentrations measured during personal monitoring of these operators (1.94 mg/m^3 and 2.14 mg/m^3, respectively). Since the personal samples were collected in each worker's breathing zone, these results provide a more accurate estimate of worker exposure than seat samples, which provide an estimate of contaminant concentrations at a fixed location on each piece of equipment.

All workers' TP exposures were less than the 5 mg/m^3 concentration established by the ACGIH as an 8-hour TWA TLV. Since personal monitoring was conducted for periods ranging from 309 to

634 minutes, it is unknown whether personal TP exposures may have intermittently exceeded the 15-minute ceiling established by NIOSH as a REL (especially in areas of poor ventilation). The enclosed tunnel environment may have contributed to the relatively high exposures measured in personal samples collected from the roller operator. At open-air paving sites, the roller operator has typically been found to have lower exposures to asphalt fume than the paver operator, rakers, and other workers closer to the point of application. Additionally, for workers in similar job categories, measured PBZ TP and BSF concentrations were typically higher than those found during open-air paving.

Medical

The results of the acute symptom survey revealed a substantially higher number of symptom occurrences reported by paving crew #1 workers (38) as compared to paving crew #2 workers (none). The most frequently reported symptoms in association with the work exposures were eye irritation, cough, nasal irritation, and shortness of breath. Reports of similar symptoms have also been found in other studies evaluating workers exposed to asphalt fume during road paving operations.[11,24-26] The reason for the difference in symptom reporting between the two paving crews is unknown. Personal and area sampling found that both crews were exposed to fairly similar TP and BSF concentrations. Area sampling for PACs found slightly higher concentrations at the crew #1 paver seat, but it is very unlikely that this explains the difference in symptom reporting. The composition of the crews was notably different with respect to cultural background, age, and length of employment at their current job title. Members of crew #1 were younger (average age 33 years), employed at their current job title for an average of 8 years, spoke English, and mostly were of Northern European heritage, whereas members of crew #2 were older (average age 51 years), employed at their current job title for an average of 18 years, spoke Portuguese and some English, and mostly were of Portuguese heritage. The NIOSH investigator, who also spoke Spanish and some Portuguese, was able to communicate with the members of crew #2 and felt that they understood and responded sincerely to posed questions. Presently, it is unclear if these cultural and employment differences influenced the acute symptom reporting results.

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. All workers in crew #1 reported acute irritant symptoms in association with work site exposures and one worker demonstrated significant bronchial lability. None of the workers in paving crew #2 reported any acute irritant symptoms in association with their work site exposures; however, two workers demonstrated significant bronchial lability. While, cigarette–related bronchitis and emphysema are probably the most common causes of pulmonary function abnormalities among adults, only one (non-symptomatic worker) of the three workers with bronchoreactivity had a history of smoking. Certain occupational chemical and dust exposures have been shown to cause or contribute to pulmonary function abnormalities, however, asphalt fume exposure has not been previously reported to do so. The notably higher concentrations of TP, BSF, and PACs measured at this site, as compared to open-air paving sites, may be responsible for these findings.

CONCLUSIONS

As expected, highest concentrations of TP, BSF, and PACs were measured above the paver screed auger. Concentrations of TP, BSF, and PACs in area samples varied between sampling locations and between the two paving crews. Although PBZ exposures to asphalt fume did not exceed the ACGIH TLV, some PBZ exposures to TP may have exceeded the 15-minute ceiling established by NIOSH as a REL. In every PAC sample, concentrations of low-molecular-weight PACs exceeded those of high molecular weight PACs, implying that the 2-3 ring PACs, felt to be more responsible for irritant effects, may be more abundant.

The results of the acute symptom survey revealed a number of reported health symptoms by crew #1 workers in association with their work exposures. However, no health symptoms were reported by crew #2 workers. While exposures varied somewhat between the paving crews, the measured differences in exposures, in all likelihood, cannot account for the large difference in symptom reporting. The reasons for this difference are unclear. Three of the workers, two of whom never smoked cigarettes, demonstrated increased bronchoreactivity during the survey. While pulmonary function abnormalities from exposure to asphalt fumes have not previously been reported in the medical literature, this finding is suggestive of a potential occupational association between road paving work and pulmonary abnormalities. Data from this evaluation, however, are based on a very small, and possibly unrepresentative, sample of pavers and reflects production and environmental conditions specific to this site.

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.

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

2. Ventilation, which was provided by air handling units located at the east end of the tunnel, provided only minimal airflow in the immersed tubes. The permanent tunnel ventilation system should have been fully operational during asphalt paving. Future paving should be conducted only if this system is fully operational.

3. To avoid contamination and possible ingestion of potentially harmful substances, workers should should be provided with adequate washing facilities (i.e., portable hand washes) for use prior to eating. Additionally, workers should avoid consuming food and beverages in close proximity to asphalt fume emissions.

4. Until the long-term health effects of exposure to asphalt fume can be determined, workers should consider the combined exposure to asphalt fume and tobacco smoke to have potentially increased health risks, providing yet another reason not to smoke.

5. To reduce skin contamination and potential contamination of workers' homes and vehicles, workers should be provided with adequate washing and changing facilities for use prior to leaving work.

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

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Table 1 Toxicity and Exposure Criteria Information Paving Site: Boston Third Harbor Tunnel, Boston, Massachusetts (HETA 94-0219)		
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.	NIOSH REL : 5 mg/m^3 15-minute ceiling. There is no current OSHA PEL for asphalt fume. ACGIH TLV®: 5 mg/m^3 8-hour TWA.
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 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. 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 low-molecular-weight PACs) are associated with more irritative effects, while the 4-to 7-ring PACs (termed high-molecular-weight PACs) may have more carcinogenic and/or mutagenic effects. It is not currently possible to definitively distinguish between these two PAC groups analytically; however, using two different spectrofluorometric detector wavelengths (370 nanometer [nm] and 400 nm) allows the detector to be more sensitive to PACs based on ring number.	None established for PAHs or PACs as a class.
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.	None established
Carbon Monoxide	Carbon monoxide (CO) is a colorless, odorless, tasteless gas produced by incomplete combustion of carbon-containing materials, e.g., natural gas. The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, and nausea. These initial symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. Coma or death may occur if high exposures continue.	NIOSH REL : 35 ppm, 8-hour TWA. OSHA PEL: 50 ppm, 8-hour TWA. ACGIH TLV®: 25 ppm, 8-hour TWA.

Table 1
Toxicity and Exposure Criteria Information
Paving Site: Boston Third Harbor Tunnel, Boston, Massachusetts (HETA 94-0219)

Compound	Toxicity Review	Exposure Criteria
Nitrogen Dioxide	Nitrogen dioxide is one of the gaseous constituents in diesel exhaust. At low concentrations, nitrogen dioxide is a respiratory irritant. Severe exposures can result in pulmonary edema and death.	NIOSH REL: 1 ppm, STEL. OSHA PEL: 5 ppm ceiling . ACGIH TLV®: 3 ppm, 8-hour TWA; 5 ppm, STEL.

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 2a. Personal Air Sampling, December 8 - 9, 1995.

Job Title	Time (minutes)	Sample Volume (L)	Total Particulate (mg/m^3)	Benzene Soluble Fraction (mg/m^3)	BSF/TP (ratio)
crew #1					
paver operator	572	1180	1.94	1.14	0.59
screedman	612	1250	1.51	0.91	0.60
raker	608	1260	1.81	1.08	0.60
laborer	565	1170	1.11	0.51	0.46
roller operator	622	1270	2.14	0.87	0.41
crew #2					
raker	634	1320	2.16	1.15	0.53
raker	610	1270	1.09	0.30	0.28
raker	572	1170	2.17	1.26	0.58
laborer	309	640	1.2	0.38	0.32

Table 2b. Area Sampling, December 8 - 9, 1995.

Location	Time (minutes)	Sample Volume (L)	Total Particulate (mg/m^3)	Benzene Soluble Fraction (mg/m^3)	BSF/TP (ratio)
crew #1					
paver seat	628	1300	0.84	0.42	0.50
roller seat	628	1310	0.44	0.092	0.21
screed auger	366†	754	13.1	12.6	0.96
screed auger	181‡	373	11.2	10.5	0.94
crew #2					
paver seat	452	931	4.43	3.40	0.77
field blanks*					
95-114			0.02 mg/filter	nd	
95-134			0.04 mg/filter	nd	
95-106			0.03 mg/filter	nd	
95-113			nd	nd	

BSF/TP = Ratio of benzene soluble fraction to total particulate.
L = liters.
mg/m^3 = Milligrams of contaminant per cubic meter of air.
nd = Not detected. See Appendix B for analytical limits.
† 5:11 p.m. - 11:17 p.m.
‡ 12:55 a.m. - 3:56 a.m.
* Blank results are reported as mg/filter.

Table 3. Area Sampling, December 8 - 9, 1995.

Location	Time (minutes)	Sample Volume (L)	Polyaromatic Compounds ($\mu g/m^3$)	
			Low MW	High MW
crew #1				
paver seat	514	1060	62.	13.3
roller seat	581	1200	20.2	4.9
screed auger	374	778	355.	95.
crew #2				
paver seat	535	1080	47.0	9.53
field blanks*				
P5			nd	nd
P6			nd	nd
P7			(0.10)	nd

L = Liters.
$\mu g/m^3$ = Micrograms of contaminant per cubic meter of air.
MW = Molecular weight. The values obtained for low and high molecular weight compounds are not additive. These values are used as indicators of low and high molecular weight compounds.
nd = Not detected. See Appendix B for analytical limits.
( ) = 0.10 µg was detected in the back section of the Orbo-42 tube. This value is between LOD and LOQ. (Analytical limits are presented in Appendix B, Table B2.)
* Blank results are reported as µg/sample

Table 4. Area Sampling: Elemental Carbon, December 8-9, 1995

Location	Sampling Time (minutes)	Sample Volume (Liters)	Concentration, micrograms per cubic meter ($\mu g/m^3$)			EC/TC
			Organic Carbon (OC)	Elemental Carbon (EC)	Total Carbon (TC)	
Crew #1 **screed auger**	645	1342	3790	49.3	3840	0.013
paver seat	632	1302	1790	66.3	1850	0.036
roller seat	328	663	621	27.1	648	0.042
Crew #2 **paver seat**[F]	--	--	--	--	--	--
field blanks*						
B5			10.3	0.0	10.3	
B6			20.2	0.0	20.2	

* Field blank results are reported as µg/sample.
F Pump faulted and would not restart. Time of fault could not be determined.
EC/TC = Ratio of elemental carbon to total carbon.

APPENDIX A

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 and referenced in draft NIOSH Method 5040. An optical feature corrects for pyrolytically generated elemental carbon (EC), or "char," which is formed during the analysis of some materials (e.g., cigarette smoke, pollen). He-Ne laser light passed through the filter allows continuous monitoring of filter transmittance. Because temperatures in excess of 850°C are employed during the analysis, quartz-fiber filters are required for sample collection. A punch from the sample filter is taken for analysis, and organic carbon (OC) and elemental carbon are reported in terms of $\mu g/cm^2$ of filter area. The total OC and EC on the filter are calculated by multiplying the reported values by the deposit area. In this approach, a homogeneous sample deposit is assumed. At the end of the analysis (after the EC is evolved), calibration is achieved through injection of a known volume of methane into the sample oven.

Thermal-optical analysis proceeds essentially in two stages. In the first, organic and carbonate carbon (if present) are evolved in an inert helium atmosphere as the temperature is raised (stepped) to about 850°C. Evolved carbon is catalytically oxidized to CO_2 in a bed of granular MnO_2 (at 950°C), CO_2 is reduced to CH_4 in a Ni/firebrick methanator (at 450°C), and CH_4 is quantified by an FID. In the second stage of the analysis, the oven temperature is reduced, an oxygen-helium mix (2% O_2 in He) is introduced into the sample oven, and the oven temperature is again raised to about 850°C. As oxygen enters the oven, pyrolytically generated EC is oxidized and a concurrent increase in filter transmittance occurs. The point at which the filter transmittance reaches its initial value is defined as the "split" between EC and OC. Carbon evolved prior to the split is considered OC (or carbonate), and carbon volatilized after the split (excluding that from the CH_4 standard) is considered elemental. The presence of carbonate can be verified through analysis of a second portion (punch) of the filter after its exposure to HCl vapor. In the second analysis, the absence of the suspect peak is indicative of carbonate carbon in the original sample.

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. This effort will assist in the transfer of this technology to other interested parties.

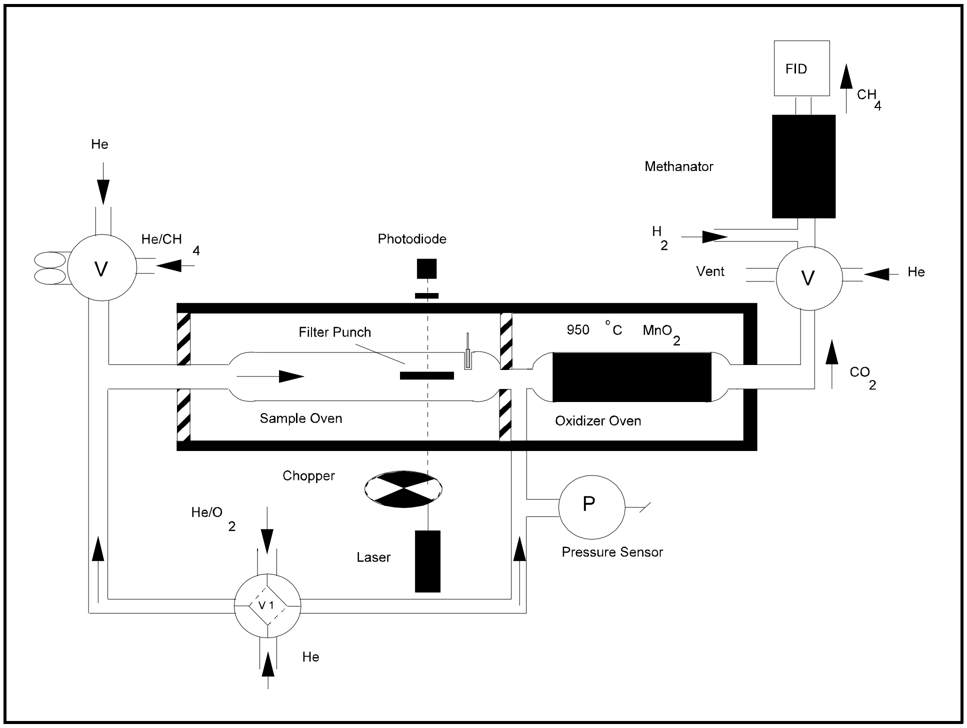

Figure 1. Schematic of Thermal-Optical Analyzer.

APPENDIX B

Analytical Limits

Table B1. Particulate total weight; benzene soluble fraction.

Analyte	LOD (mg/sample)	MDC (mg/m^3)
particulate total weight	0.01	0.01
benzene soluble fraction	0.05	0.05

LOD = Analytical limit of detection.
MDC = Minimum detectable concentration based upon an average sample volume of 1080 liters.
mg/m^3 = Milligrams of contaminant per cubic meter of air.

Table B2. Polyaromatic compounds.

Analytical emphasis	LOD (µg/sample)	LOQ (µg/sample)	MDC ($\mu g/m^3$)	MQC ($\mu g/m^3$)
low MW compounds	0.04	0.12	0.04	0.12
high MW compounds	0.02	0.06	0.02	0.06

LOD = Analytical limit of detection.
LOQ = Analytical limit of quantitation.
MDC = Minimum detectable concentration based upon an average sample volume of 1030 liters.
MQC = Minimum quantifiable concentration based upon an average sample volume of 1030 liters.
$\mu g/m^3$ = Micrograms of contaminant per cubic meter of air.

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