SURVEY REPORT:

CONTROL TECHNOLOGY EVALUATION FOR CONTROLLING WORKER EXPOSURE TO ASPHALT FUMES FROM ROOFING KETTLES: KETTLE OPERATED USING LOW FUMING ASPHALT

at

Toledo Correctional Institute
Toledo, Ohio

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SIC CODE:	1761
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INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), a federal agency located in the Centers for Disease Control and Prevention (CDC) under the Department of Health and Human Services, was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct research and education programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential biological, chemical, and physical hazards.

The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects relevant to the control of hazards in the workplace. Since 1976, EPHB has assessed control technology found within selected industries or used for common industrial processes. EPHB has also designed new control systems where current industry control technology was insufficient. The objective of these studies was to document and evaluate effective control techniques (e.g., isolation or the use of local ventilation) that minimized the risk of potential health hazards and created an awareness of the usefulness and availability of effective hazard control measures.

One industry identified for EPHB control studies is asphalt roofing. Epidemiologic studies of roofers have demonstrated an excess of lung, bladder, renal, brain, liver, and digestive system cancers among roofers or other occupations with the potential for exposure to asphalt.[1-16] It is unclear to what extent these findings may be attributable to asphalt fume exposure. Roofers in the past have also been exposed to coal tar and asbestos which are known carcinogens.

As a result of the epidemiological data, researchers from EPHB developed a project to evaluate engineering controls in the asphalt roofing industry. Due to the high asphalt temperatures used in the roofing process, roofing kettle operators may be at higher risk of asphalt fume exposure than workers in any other industry or trade. This project evaluates existing engineering controls for asphalt fume exposures to roofing kettle operators and, if necessary, redesigns those controls to reduce operator exposure. In 1990, an estimated 46,000 roofing workers were exposed to asphalt fumes in the United States. Only 10% of those workers were covered under a collective bargaining agreement. These workers were employed primarily by small contractors who generally lack detailed occupational safety and health programs or a designated occupational safety and health expert – about 90% of roofing contractors have fewer than 20 employees. Studying ways to reduce exposure to these construction workers addresses item 10.2 of the Healthy People 2000 Objectives, the NIOSH National Occupational Research Agenda (NORA), and OSHA priorities.[17-19]

While this project concerns itself primarily with the reduction of asphalt fume exposure to kettle operators, parallel studies in cooperation with the EPHB study provide an in-depth examination of asphalt fume exposures to workers on the roof during hot asphalt application. There are three

NIOSH studies examining engineering controls, blood and urine biomarkers, and medical effects due to asphalt fume exposure and a Harvard University study examining urine biomarkers and PAC/Pyrene exposure.

Kettle operators are responsible for maintaining the appropriate supply of hot asphalt at the correct temperature for application on the roof during construction of built-up roofs (BUR). BURs are layers or plies of fiberglass felt sealed together with hot asphalt. The layers provide protection against moisture penetration and, combined with the asphalt's ability to seal itself, makes BUR an excellent waterproofing system.[20] Roofing kettles are steel containers used to heat and store hot asphalt until needed for application on the roof. They vary in size from 150 to 1500 gallons. They are equipped with a positive displacement pump, powered by a gasoline engine, which recirculates the hot asphalt in the kettle and transfers the hot asphalt, via a "hot pipe," to the roof. Roofing kettles are normally equipped with one or two propane fired burners for heating the asphalt. The propane burners exhaust into fire-tubes which are submerged in the asphalt within the kettle. These tubes direct the hot combustion gases through one or two passes running the length of the kettle, transferring heat energy to the asphalt before being released to the atmosphere. The asphalt temperature is controlled by throttling the propane supply to the burner(s). The throttle valve is manually operated by the kettle operator or hydraulically actuated via a thermostat. The kettle is usually located at ground level during the roofing operation. When additional asphalt is needed by the workers on the roof, hot asphalt is pumped from the kettle through the hot pipe to the roof level for application. Activation of the pump may be done manually by the kettle operator or remotely from the roof by a pull rope attached to the kettle. The recirculating/transfer pump is normally operated only during the transfer of hot asphalt to the roof.

Roofing asphalt may be delivered to the work site in solid kegs or in tanker trucks. When tanker trucks are used, a roofing kettle may not be necessary unless additional heating is required. The more traditional method is to deliver the asphalt in solid, paper-wrapped kegs which weigh approximately 100 pounds. During loading, the kettle operator must remove the paper wrapping and chop the solid asphalt keg into smaller, more manageable pieces. These pieces are manually loaded into the kettle through a raised kettle lid or, when available, through a "post office" type safety loading door designed to reduce worker exposure to asphalt fumes and prevent the operator from being splashed with hot asphalt. In addition to loading asphalt, the kettle operator periodically opens the lid to remove impurities which tend to accumulate on the surface of the hot asphalt; this is called skimming.

The equiviscous temperature (EVT) is the application temperature (EVT varies each production batch) at which optimum wetting and adhesive qualities of the roofing asphalt is obtained. The asphalt temperature in the kettle is maintained somewhat higher than the EVT of the asphalt. The actual maintenance temperature of the kettle will vary according to outdoor temperature, length of hot pipe, asphalt usage rate, pump flow rate, and type of receiving vessels on the roof. Table 1 shows the EVT and other thermal properties for four types of asphalt. The flashpoint (FP) is the temperature at which the asphalt may burst into flame. The maximum heating temperature is 25°F less than the FP and should never be exceeded. The type of asphalt used in an application is determined by, among other things, the slope of the roof being built.

Table 1
Maximum Heating Temperature, Flashpoint, and EVT of Various Types of Asphalt

Type Number	Kind of Asphalt	Maximum Heating Temperature °F	Flash-point Temperature °F	EVT ±25 °F
Type I	Dead Level	475	525	375
Type II	Flat	500	550	400
Type III	Steep	525	575	425
Type IV	Special	525	575	425

STUDY BACKGROUND

A survey was conducted on September 28 and November 5-8, 1999, at the Toledo Correctional Institute in Toledo, Ohio, where a new 3-ply roof with a coal-tar and gravel cap was being applied to a new correctional institute under construction. The engineering control used during this evaluation was low fuming asphalt. Other existing engineering controls for this industry will be evaluated during subsequent surveys. A final report will summarize the engineering controls evaluated from all of the surveys.

HEALTH EFFECTS/OCCUPATIONAL EXPOSURE CRITERIA

There are three primary sources used in the United States for environmental evaluation criteria: NIOSH Recommended Exposure Limits (RELs); the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs); and the U.S. Department of Labor OSHA Permissible Exposure Limits (PELs). OSHA has specific PELs for regulating the construction industry.[21] The OSHA PELs are the only legally enforceable exposure criteria among those listed, and during their development, OSHA must consider the feasibility of controlling exposures in addition to the related health effects. In contrast, NIOSH RELs are based primarily on concerns relating to health effects. The ACGIH TLVs refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be exposed, day after day, without adverse health effects. The ACGIH is a private professional society and states that the TLVs are only guidelines.

In a 1988 rule on air contaminants, OSHA proposed a PEL of 5 mg/m^3 as an 8-hr time-weighted average (TWA) for asphalt fumes exposure in general industry. This proposal was based on a preliminary finding that asphalt fumes should be considered a potential carcinogen.[22] In 1989, OSHA announced that it would delay a final decision on the 1988 proposal because of complex and conflicting issues submitted to the record.[23] In 1992, OSHA published another proposed rule for asphalt fumes that indicated a PEL of 5 mg/m^3 (total particulate) for general industry, construction, maritime, and agriculture.[24] Although OSHA invited comments on all of the alternatives, its proposed standard for asphalt fumes would establish a PEL of 5 mg/m^3 (total particulate) based on avoidance of adverse respiratory effects. The OSHA docket is closed, and OSHA has not scheduled any further action.

In 1977, NIOSH established an REL of 5.0 mg/m^3 (total particulate) measured as a 15-minute ceiling limit for asphalt fumes to protect against irritation of the serous membrane of the conjunctiva and the mucous membrane of the respiratory tract. In 1988, NIOSH (in testimony to the Department of Labor) recommended that, based on the OSHA cancer policy,[25] asphalt fumes should be considered a potential occupational carcinogen.[26] This recommendation was based on information presented in the Niemeier et al. study.[27] This NIOSH conclusion is based on the collective evidence found in available health effects and exposure data.[28]

The current ACGIH TLV for asphalt fumes is an 8-hr TWA-TLV of 0.5 mg/m^3 as benzene-extractable inhalable particulate (or equivalent method) with an A4 designation, indicating that it is not classifiable as a human carcinogen.[29]

Asphalt fumes have been reported to cause irritation of the mucous membranes of the eyes, nose, and respiratory tract.[30] While other symptoms such as coughing and headaches were reported recently, there was no statistical association with asphalt fume exposure.[31, 32] Results from experimental studies with animals[27, 33, 34] indicate that roofing asphalt fume condensates generated in the laboratory and applied dermally cause benign and malignant skin tumors in several strains of mice. Differences in chemical composition and physical characteristics have been noted between roofing asphalt fumes collected in the field and those generated in the laboratory.[35] However, the significance of these differences in ascribing health effects to humans is unknown. Furthermore, no published data exist that examine the carcinogenic potential of field-generated roofing asphalt fumes in animals. Since the health risks from asphalt exposure are not yet fully defined, NIOSH, labor, and industry are working together to better characterize these risks while continuing their effort to reduce worker exposures to asphalt fumes.

In the roofing industry, exposure to asphalt fumes and other related exposures is well documented and studies still continue. Several studies have identified increased polycyclic aromatic compounds (PACs) exposure to the kettle operators versus other categories of roofers.[27] Due to the nature of the kettle operator's job, this appears to be an obvious conclusion; however, few controls have been utilized to minimize these exposures.

SITE DESCRIPTION AND WORK ACTIVITY

The Toledo Correctional Institute is a large multiple wing jail that was under construction during the week that the survey was conducted. The roof being applied to the new jail was a 3-ply built-up asphalt roof with a coal tar pitch gravel cap. Shown in Table 2 are the areas of roof applied and the amount of asphalt used each day of the survey.

Table 2
Area of Roof Installed and Amount of Asphalt Used Each Day

Date	Area of Roof Installed (ft^2)	Amount of Asphalt Used (pounds)
10/5/99	2966	2600
10/6/99	4950	3600
10/7/99	3750	3000
10/8/99	2268	1800

The roofers began work at 6:30 a.m. each day. At that time, the kettle operator loaded asphalt into a 550 gallon kettle (manufacturer unknown) and lit the propane burners to bring the asphalt up to the correct temperature. The kettle was located at ground level in a large court yard area which had a 40 foot wide entrance and was surrounded by 25 foot walls. During the week that the survey was conducted, the roofers worked on an area of the roof where 1-ply of hard board had already been applied. The roofers applied two more layers of asphalt and hard board and capped the three layers with coal tar pitch and gravel. To avoid interferences in the air sample results from the coal tar pitch, air sampling was done each day until about noon, at which time the sampling was stopped before the propane burners to the kettle containing the coal tar pitch were lit.

EVALUATION METHODS

In order to develop useful and practical recommendations, the ability of the engineering control measure to reduce worker exposure to air contaminants must be documented and evaluated. Where practical, this was accomplished by evaluating workers' exposure to asphalt fume particulate and PACs both with and without low fuming asphalt. Personal breathing zone and area air samples were collected and analyzed for total particulate (TP), benzene soluble fraction (BSF) of the total particulate using NIOSH Manual of Analytical Methods (NMAM) Method 5042, and NMAM Method 5800 for PACs.[36] The temperature of the hot asphalt was recorded periodically with an electronic thermocouple and compared to the temperature gauge permanently mounted on the kettle.

Air Sampling

The personal breathing zone and area air sampling consisted of two sampling trains per worker or area. One sampling train was used to collect TP and BSF and the other train was used to collect total PACs. Both sampling trains' air sampling pumps were calibrated to an air sampling flow rate of 2 liters per minute (lpm). Personal breathing zone air samples were collected on the kettle operator and three roof level workers. Area air samples were collected at ground level at each of the four corners around the kettle. The area air samplers were placed in tripods and the sampling media was positioned to breathing zone height (approximately 60 inches above the ground). Area air samples were also collected around the work area on the roof. These area air samples were also placed on tripods with the sampling media positioned to breathing zone height. One of the area air samples collected each day on the roof was placed next to the "hot" pipe which was used to pump the asphalt from the kettle to the lugger on the roof.

Kettle Temperature

The kettle was equipped with a permanently mounted temperature gage. This gage reading is used by the kettle operator to monitor and maintain hot asphalt above the EVT. The mounted gage calibration was checked against a Tegam Model 821 microprocessor thermometer using a K-type thermocouple.

Summarized in Table 3 are the mean kettle temperature measurements along with the mean kettle gauge temperature measurement.

Table 3
Summary of Kettle Temperature Data

Date	Number of Measurements	Mean Kettle Temperature (°F)	Minimum Kettle Temperature (°F)	Maximum Kettle Temperature (°F)	Mean Gauge Kettle Temperature (°F)
10/5/1999	2	487	480	493	na
10/6/1999	4	494	471	520	490
10/7/1999	4	500	470	520	503
10/8/1999	4	534	520	546	535

Statistical Evaluation

Personal breathing zone and area air sample data for TP, BSF, and total PAC were statistically compared with and without low fuming asphalt using Student's t-test. Statistical comparisons were also done for the standardized personal breathing zone and area air sampling data.

RESULTS

Kettle Operator Personal Breathing Zone Sample Results

Personal breathing zone air samples were collected on the kettle operator and analyzed for TP, BSF, and total PAC. Samples were collected for four days, and the results are listed in Table 4. Two days of sampling were conducted when the kettle contained conventional asphalt, and two days of sampling were conducted when the kettle contained TruMelt™ low fuming asphalt. The concentration of TP for the kettle operator when conventional asphalt was used was 1.61 mg/m^3, and with low fuming asphalt, the mean was 0.85 mg/m^3. Total particulate and BSF results for the kettle operator were only available for the second day of sampling while using conventional asphalt; the first day's sample was lost. The reduction in the TP concentration for the kettle operator using low fuming asphalt was 47.2%. The BSF concentration for the kettle operator when conventional asphalt was used was 1.13 mg/m^3, and when low fuming asphalt was used, the mean was 0.14 mg/m^3. Mean values were calculated using the limit of detection divided by the square root of two for those results reported as less than values. The reduction in the kettle operator's exposures between the BSF concentrations when conventional asphalt was used and when low fuming asphalt was used was 87.6%. The mean total PAC concentration for the kettle operator when conventional asphalt was used was 299 µg/m^3 and when low fuming asphalt was used, the mean was 39.6 µg/m^3. The reduction in the mean total PAC concentration for the kettle operator when using low fuming asphalt was 86.8%.

Table 4
Kettle Operator (GP-01) TP, BSF, and PAC Exposure Concentrations

Sample Date	Sample Time (min.)	TP Conc. (mg/m^3)	BSF Conc. (mg/m^3)	360 PAC Conc. (µg/m^3)	400 PAC Conc. (µg/m^3)	Total PAC Conc. (µg/m^3)	With or Without Low Fuming Asphalt
10/5/99	278	na	na	267	35.6	302	Without
10/6/99	260	1.61	1.13	269	26.9	296	Without
10/7/99	277	0.99	<0.18	52.2	5.94	58.2	With
10/8/99	349	0.72	0.14	18.7	2.44	21.1	With

TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m^3 = milligrams per cubic meter of air
$\mu g/m^3$ = micrograms per cubic meter of air
nm = nanometers
na = not available

Area Air Sample Results For Samples Collected Around The Kettle

Area air samples were collected at the four corners of the asphalt roofing kettle at breathing zone height. Samples were collected and analyzed for TP, BSF, and PAC. As for the other samples, for two days, conventional asphalt was used, and for two days, low fuming asphalt was used. These results are shown in Table 5.

Table 5
Area Air Sample Concentration Results For TP, BSF, and PAC Collected Around the Kettle

Sample Date	Sample Location Around Kettle	Sample Time (min.)	TP Conc. (mg/m^3)	BSF Conc. (mg/m^3)	360 PAC Conc. ($\mu g/m^3$)	400 PAC Conc. ($\mu g/m^3$)	Total PAC Conc. ($\mu g/m^3$)	With or Without Low Fuming Asphalt
10/5/99	NE corner	255	0.90	0.82	234	23.4	258	Without
10/6/99	NE corner	273	3.06	2.77	396	39.6	436	Without
10/7/99	NE corner	302	0.31	0.33	38.0	3.97	42.0	With
10/8/99	NE corner	359	0.28	0.14	13.9	1.36	15.2	With
10/5/99	NW corner	90	1.26	1.10	623	60.7	687	Without
10/6/99	NW corner	273	2.65	2.22	415	41.5	456	Without
10/7/99	NW corner	302	0.12	0.33	9.04	0.79	9.83	With
10/8/99	NW corner	359	0.39	0.28	18.1	1.81	19.9	With
10/5/99	SE corner	254	0.22	<0.20	41.2	4.51	45.7	Without

10/6/99	SE corner	273	0.49	0.36	138	13.8	151	Without
10/7/99	SE corner	302	0.03	0.33	13.6	1.35	15.0	With
10/8/99	SE corner	359	0.24	<0.14	7.95	0.68	8.63	With
10/5/99	SW corner	250	1.00	0.92	120	11.5	132	Without
10/6/99	SW corner	273	0.53	0.36	136	11.4	148	Without
10/7/99	SW corner	302	0.60	0.33	89.3	6.12	95.4	With
10/8/99	SW corner	359	0.28	<0.14	15.2	1.36	16.6	With

TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m^3 = milligrams per cubic meter of air
$\mu g/m^3$ = micrograms per cubic meter of air
nm = nanometers

The mean TP concentration for the eight area air samples collected around the kettle for the days when conventional asphalt was used was 1.26 mg/m^3 (SD = 1.04). The mean TP concentration for the eight area air samples collected around the kettle when low fuming asphalt was used was 0.28 mg/m^3 (SD = 0.17). The reduction in the mean TP concentration when using low fuming asphalt was 77.8%. The mean BSF concentration for the area air samples collected around the kettle when conventional asphalt was used was 1.09 mg/m^3 (SD = 0.94) and 0.24 mg/m^3 (SD = 0.11) when using low fuming asphalt. The reduction in the mean BSF concentration when using low fuming asphalt was determined to be 78.0%. The mean total PAC concentration for the area air samples collected around the kettle when conventional asphalt was used was 289 $\mu g/m^3$ (SD = 218). The mean total PAC concentration for the area air samples collected around the kettle when the low fuming asphalt was used was 27.8 $\mu g/m^3$ (SD = 29.2). The reduction in the mean total PAC concentration when using low fuming asphalt was 90.4%.

Roof Level Worker Personal Breathing Zone Sample Results

Personal breathing zone air samples were collected on the roof level workers who were putting on the new roof. Two of the workers who were mopping, and one worker who was lugging the asphalt, were sampled for TP, BSF, and total PAC for two days using conventional asphalt and two days using low fuming asphalt. These sample results are shown in Table 6.

Table 6
Roof-Level Worker TP, BSF, and PAC Exposure Concentrations

Sample Date	Worker ID Number	Sample Time (hr.)	TP Conc. (mg/m^3)	BSF Conc. (mg/m^3)	360 PAC Conc. (µg/m^3)	400 PAC Conc. (µg/m^3)	Total PAC Conc. (µg/m^3)	With or Without Low Fuming Asphalt
10/5/99	GP-02	204	0.90	0.49	1.44	0.35	1.79	Without
10/6/99	GP-02	240	1.35	0.62	176	19.1	195	Without
10/7/99	GP-02	236	0.42	<0.21	29.5	4.22	33.7	With
10/8/99	GP-02	269	0.09	<0.18	20.4	3.35	23.8	With
10/5/99	GP-03	204	0.34	<0.25	214	24.6	239	Without
10/6/99	GP-03	240	0.44	0.21	91.4	10.2	102	Without
10/7/99	GP-03	239	0.40	<0.21	56.4	7.52	63.9	With
10/8/99	GP-03	271	0.11	<0.19	6.66	0.65	7.31	With
10/5/99	GP-04	212	0.34	<0.24	283	34.0	317	Without
10/6/99	GP-04	241	0.19	0.42	64.5	7.70	72.2	Without
10/7/99	GP-04	238	0.31	<0.21	39.8	5.24	45.1	With
10/8/99	GP-04	267	0.17	0.19	24.4	3.75	28.2	With

TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m^3 = milligrams per cubic meter of air
µg/m^3 = micrograms per cubic meter of air
nm = nanometers

Worker GP-02 performed the lugging activities on the roof, filling the lugger with asphalt and using the lugger to fill the mop buckets with asphalt. Worker GP-03 performed asphalt mopping activities on the roof. Worker GP-04 also performed asphalt mopping activities on the roof. The personal breathing zone air sample data collected from the roof-level workers are shown in Table 6.

The mean TP concentration for all roof-level workers when conventional asphalt was used was 0.59 mg/m^3 (SD = 0.44) and when low fuming asphalt was used was 0.25 mg/m^3 (SD = 0.15). The reduction in the mean TP concentration for all roof-level workers using low fuming asphalt was 57.6%. The mean BSF concentration for all roof-level workers when conventional asphalt was used was 0.35 mg/m^3 (SD = 0.19) and when low fuming asphalt was used was 0.16 mg/m^3 (SD = 0.04). The reduction in the mean BSF concentration for all roof-level workers using low fuming asphalt was 54.3%. The mean total PAC concentration for all roof-level workers when conventional asphalt was used was 154 µg/m^3 (SD = 117) and when low fuming asphalt was used was 33.7 µg/m^3 (SD = 19.3). The reduction in the mean total PAC concentration for all roof-level workers using low fuming asphalt was 78.1%.

Roof Level Area Air Sample Results

Area air samples were collected at breathing zone height on the roof around the work area where the built-up asphalt roof was being installed. These samples were analyzed for TP, BSF, and total PAC. The results of these samples are listed in Table 7.

The mean TP concentration for all roof-level area air samples when conventional asphalt was used was 0.11 mg/m^3 (SD = 0.08 mg/m^3) and when low fuming asphalt was used was 0.06 mg/m^3 (SD = 0.04 mg/m^3). The reduction in the mean TP concentration for all roof-level area air samples using low fuming asphalt was 45.5%. The mean BSF concentration for all roof-level area air samples when conventional asphalt was used was 0.16 mg/m^3 and when low fuming asphalt was used was 0.17 mg/m^3. The BSF exposure result of 6.57 mg/m^3 collected at the northwest corner of the work area on October 16, 1999, was determined to be an outlying result using the Q test[36] and was not included in the calculation of the mean BSF results for conventional asphalt. There was an increase in the mean BSF exposures for all roof-level area air samples of 6.25%. The mean total PAC concentration for all roof-level area air samples when conventional asphalt was used was 54.8 µg/m^3 (SD = 98.5 µg/m^3) and when low fuming asphalt was used was 9.95 µg/m^3 (SD = 6.47 µg/m^3). The reduction in the mean total PAC concentration for all roof-level area air samples using low fuming asphalt was 81.8%.

Table 7
Roof-Level Area Air Sample Results for TP, BSF, and PAC Exposure Concentrations

Sample Date	Sample Location On Roof	Sample Time (hr.)	TP Conc. (mg/m^3)	BSF Conc. (mg/m^3)	360 PAC Conc. ($\mu g/m^3$)	400 PAC Conc. ($\mu g/m^3$)	Total PAC Conc. ($\mu g/m^3$)	With or Without Low Fuming Asphalt
10/5/99	NE corner	204	<0.02	<0.24	11.3	1.08	12.4	Without
10/6/99	NE corner	245	0.04	<0.20	39.5	4.16	43.7	Without
10/7/99	NE corner	230	<0.02	<0.22	8.25	0.74	8.99	With
10/8/99	NE corner	265	0.08	0.19	4.18	0.27	4.45	With
10/5/99	NW corner	201	0.15	<0.25	265	28.9	294	Without
10/6/99	NW corner	244	<0.02	6.57	5.09	0.43	5.53	Without
10/7/99	NW corner	237	0.13	<0.21	19.8	2.00	21.8	With
10/8/99	NW corner	261	<0.02	0.19	2.27	0.27	2.54	With
10/5/99	SW corner	173	0.17	<0.26	50.0	5.79	55.8	Without
10/6/99	SW corner	250	0.14	<0.20	1.46	0.29	1.75	Without
10/7/99	SW corner	235	0.06	<0.21	13.2	1.19	14.4	With
10/8/99	SW corner	259	0.08	<0.19	8.81	0.92	9.73	With
10/5/99	SE corner	185	0.24	<0.27	8.34	0.81	9.15	Without
10/6/99	SE corner	241	0.12	<0.21	14.3	1.69	15.9	Without
10/8/99	SE corner	263	0.04	0.19	7.12	0.60	7.72	With

TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m^3 = milligrams per cubic meter of air
$\mu g/m^3$ = micrograms per cubic meter of air
nm = nanometers

Statistical Analysis of the Effectiveness of Using Low Fuming Asphalt to Reduce Worker and Area Air Exposures to Asphalt Fumes

Statistical analyses were conducted on the air sampling data to determine the effectiveness of reducing worker exposure to asphalt fumes by using low fuming asphalt. A summary of these analyses are shown in Table 8. Comparisons were made between air sample results for TP, BSF, and total PAC while conventional asphalt was used and when low fuming asphalt was used. Comparisons were made for the following groups: the kettle operator; the four area air samples collected around the asphalt kettle; the three roof-level workers; and area air samples collected on the roof around the work area. Included in Table 8 are percent reductions in exposure to the mean TP, BSF, and total PAC concentrations, p-values, t-values, and critical t-values at 95% confidence.

Table 8
Summary of Statistical Analyses of the Effectiveness of Using Low Fuming Asphalt to Reduce Worker and Area Air Exposures to Asphalt Fumes

Comparison Group/Analyte	Percent Reduction in Exposure (Conventional - Low fuming)/Conventional	p-value	t-value	Critical t at 95% confidence
Kettle Operator/TP	47.2	0.0960	3.2148	6.3137
Kettle Operator/BSF	**87.6**	**0.0045**	**70.889**	**6.3137**
Kettle Operator/Total PAC	**86.8**	**0.0026**	**13.789**	**2.9200**
Area Samples Around Kettle/TP	**77.8**	**0.0099**	**2.6322**	**1.7613**
Area Samples Around Kettle/BSF	**78.0**	**0.0120**	**2.5292**	**1.7613**
Area Samples Around Kettle/Total PAC	**90.4**	**0.0023**	**3.3635**	**1.7613**
Roof-Level Workers/TP	57.6	0.0513	1.7970	1.8125
Roof-Level Workers/BSF	**54.3**	**0.0208**	**2.3370**	**1.8125**
Roof-Level Workers/Total PAC	**78.1**	**0.0157**	**2.5017**	**1.8125**
Area Samples on the Roof/TP	45.5	0.0787	1.5007	1.7709
Area Samples on the Roof/BSF	-6.25	0.4799	-0.0515	1.7823
Area Samples on the Roof/Total PAC	81.8	0.1266	1.1959	1.7709

TP = total particulate
BSF = benzene soluble fraction of total particulate
PAC = polycyclic aromatic compounds

Bold = statistically significant reduction at 95% confidence level.

Using t distribution, reductions in exposures were tested to determine if they were statistically significant at 95% confidence. The reductions measured for the kettle operator's mean BSF and total PAC exposures were found to be statistically significant at the 95% confidence level. The reductions measured in the mean TP, BSF, and total PAC exposures for the area air samples collected around the kettle. For the roof-level workers, BSF and total PAC exposures were found to be statistically significant at 95% confidence. None of the reductions measured for the roof-level area air samples were found to be statistically significant at 95% confidence.

Comparison of Results by Standardizing Exposure Concentrations by the Amount of Asphalt Used

The amount of asphalt used each day varied as shown in Table 2. Because the exposure levels of TP, BSF, and total PAC measured for the workers and area air samples may be affected by the amount of asphalt used each day, TP, BSF, and total PAC concentration for the workers and area air samples collected around the kettle were standardized by dividing these concentrations by the pounds of asphalt used that day. These standardized concentrations were then compared, conventional asphalt to low fuming asphalt, to see if the reductions in exposure were still statistically significant to the same degree they were before the standardization. Listed in Table 9 are the standardized TP, BSF, and total PAC concentrations for workers GP-01 (kettle operator), -02, -03, and, -04 (roof-level workers). Listed in Table 10 are the standardized TP, BSF, and total PAC concentrations for the four area air samples collected around the kettle. Listed in Table 11 are the standardized TP, BSF, and total PAC concentrations for the area air samples collected on the roof around the work area.

Table 9
Standardized TP, BSF, Total PAC Concentrations for Workers GP-01 Through GP-04

Sample Date	Worker Identification Number	TP conc./ Lb. Asphalt used ($mg/m^3Lb.$)	BSF conc./ Lb. Asphalt used ($mg/m^3Lb.$)	Total PAC conc./ Lb. Asphalt used ($\mu g/m^3Lb.$)	With or Without Low Fuming Asphalt
10/5/99	GP-01	na	na	0.11626	without
10/6/99	GP-01	0.00045	0.00031	0.08217	without
10/7/99	GP-01	0.00033	0.00004	0.01939	with
10/8/99	GP-01	0.00040	0.00008	0.01172	with
10/5/99	GP-02	0.00035	0.00019	0.00069	without
10/6/99	GP-02	0.00037	0.00017	0.05427	without
10/7/99	GP-02	0.00014	0.00005	0.01125	with
10/8/99	GP-02	0.00005	0.00007	0.01322	with
10/5/99	GP-03	0.00013	0.00007	0.09187	without
10/6/99	GP-03	0.00012	0.00006	0.02822	without
10/7/99	GP-03	0.00013	0.00005	0.02130	with
10/8/99	GP-03	0.00006	0.00007	0.00406	with
10/5/99	GP-04	0.00013	0.00007	0.12193	without
10/6/99	GP-04	0.00005	0.00012	0.02005	without
10/7/99	GP-04	0.00010	0.00008	0.01502	with
10/8/99	GP-04	0.0009	0.00010	0.01564	with

TP = total particulate
BSF = benzene soluble fraction of TP
Total PAC = polycyclic aromatic compounds
mg/m^3lb = milligrams per cubic meter of air times pounds of asphalt used
$\mu g/m^3lb$ = micrograms per cubic meter of air times pounds of asphalt used
na = not available
lb = pounds of asphalt

Table 10
Standardized TP, BSF, Total PAC Concentrations for Area Air Samples Collected Around the Kettle

Sample Date	Sample Location Around the Kettle	Standardized TP conc. (mg/m^3lb)	Standardized BSF conc. (mg/m^3lb)	Standardized Total PAC conc ($\mu g/m^3lb$)	With or Without Low Fuming Asphalt
10/5/99	NE Corner	0.00035	0.00032	0.09906	without
10/6/99	NE Corner	0.00085	0.00077	0.12101	without
10/7/99	NE Corner	0.00010	0.00011	0.01400	with
10/8/99	NE Corner	0.00015	0.00008	0.00846	with
10/5/99	NW Corner	0.00048	0.00042	0.26439	without
10/6/99	NW Corner	0.00074	0.00062	0.12679	without
10/7/99	NW Corner	0.00004	0.00011	0.00328	with
10/8/99	NW Corner	0.00022	0.00015	0.01104	with
10/5/99	SE Corner	0.00008	0.00005	0.01758	without
10/6/99	SE Corner	0.00014	0.00010	0.04205	without
10/7/99	SE Corner	0.00001	0.00011	0.00500	with
10/8/99	SE Corner	0.00013	0.00005	0.00479	with
10/5/99	SW Corner	0.00038	0.00035	0.05065	without
10/6/99	SW Corner	0.00015	0.00010	0.04099	without
10/7/99	SW Corner	0.00020	0.00011	0.03180	with
10/8/99	SW Corner	0.00015	0.00005	0.00921	with

TP = total particulate
BSF = benzene soluble fraction of TP
Total PAC = polycyclic aromatic compounds
mg/m^3lb = milligrams per cubic meter of air times pounds of asphalt used
$\mu g/m^3lb$ = micrograms per cubic meter of air times pounds of asphalt used
lb = pounds of asphalt

Table 11
Standardized TP, BSF, Total PAC Concentrations for Area Air Samples Collected Around the Roofing Area

Sample Date	Sample Location Around the Roofing Area	Standardized TP conc. (mg/m^3lb)	Standardized BSF conc. (mg/m^3lb)	Standardized Total PAC conc. ($\mu g/m^3lb$)	With or Without Low Fuming Asphalt
10/5/99	NE corner	0.000005	0.000065	0.004770	without
10/6/99	NE corner	0.000011	0.000039	0.012139	without
10/7/99	NE corner	0.000005	0.000052	0.002997	with
10/8/99	NE corner	0.000044	0.000106	0.002472	with
10/5/99	NW corner	0.000051	0.000068	0.113077	without
10/6/99	NW corner	0.000006	0.001825	0.001536	without
10/7/99	NW corner	0.000043	0.000050	0.007267	with
10/8/99	NW corner	0.000008	0.000106	0.001411	with
10/5/99	SW corner	0.000065	0.000071	0.021462	without
10/6/99	SW corner	0.000039	0.000039	0.000486	without
10/7/99	SW corner	0.000020	0.000050	0.004800	with
10/8/99	SW corner	0.000044	0.000075	0.005406	with
10/5/99	SE corner	0.000092	0.000074	0.003519	without
10/6/99	SE corner	0.000033	0.000041	0.004417	without
10/8/99	SE corner	0.000013	0.000106	0.004289	with

TP = total particulate
BSF = benzene soluble fraction of TP
Total PAC = polycyclic aromatic compounds
mg/m^3lb = milligrams per cubic meter of air times pounds of asphalt used
$\mu g/m^3lb$ = micrograms per cubic meter of air times pounds of asphalt used
lb = pounds of asphalt

Statistical Analysis of the Effectiveness of using Low Fuming Asphalt to Reduce Worker and Area Air Standardized Exposures to Asphalt Fumes

Statistical analysis of the standardized exposure concentrations was conducted in the same manner as exposure concentrations. Statistical comparisons were done for the kettle operator (GP-01), the combined results for the three roof-level workers (GP-02, -03, and -04), the combined results for the four area air samples collected around the kettle, and the combined results for the area air samples collected on the roof around the work area. These statistical analyses are listed in Table 12. For each comparison group and each analyte, Table 12 shows the percent reduction in the mean exposure concentration (conventional vs. low fuming), the p- and t-values for the reductions, and the critical t-values at 95% confidence.

Statistical comparison of the kettle operator's (GP-01) standardized mean TP concentration with conventional asphalt to the standardized mean TP concentration with low fuming asphalt was a reduction of 19% ($p = 0.19$, $t = 1.41$). The reduction in standardized mean BSF concentration was 81% when using low fuming asphalt compared to conventional asphalt, which was statistically significant at 95% confidence ($p = 0.04$, $t = 7.85$). The reduction in standardized mean total PAC concentration using low fuming asphalt was 84% which was statistically significant at 95% confidence ($p = 0.02$, $t = 4.79$).

The reduction in the standardized mean TP concentration for the four area air samples collected around the kettle when using low fuming asphalt was 68%, which is statistically significant at 95% confidence ($p = 0.01$, $t = 2.61$). The reduction in the standardized mean BSF concentration for all the area air samples collected around the kettle when using low fuming asphalt was 71%, which was statistically significant at 95% confidence ($p = 0.009$, $t = 2.66$). The reduction in the standardized mean total PAC concentration for all the area air samples collected around the kettle when using low fuming asphalt was 89%, which was statistically significant at 95% confidence ($p = 0.005$, $t = 2.99$).

Combining the standardized personal breathing zone air sample results for the three roof-level workers, their standardized mean TP concentration was reduced by 50% when using low fuming asphalt ($p = 0.06$, $t = 1.69$). The combined results show that the three roof-level workers' standardized mean BSF concentration was reduced by 36% when using low fuming asphalt ($p = 0.07$, $t = 1.63$). The combined roof-level workers' standardized mean total PAC concentration was reduced by 75% when using low fuming asphalt, which was statistically significant at 95% confidence ($p = 0.03$, $t = 2.07$).

Combining the standardized area air sample results for the roof-level area samples, the mean TP concentration was reduced 31% when using low fuming asphalt ($p = 0.20$, $t = 0.87$). The combined results show that the roof-level area air samples' standardized mean BSF concentration was increased by 37% when using low fuming asphalt ($p = 0.06$, $t = -1.72$). The combined roof-level area air samples' standardized mean total PAC concentration was reduced by 80% when using low fuming asphalt ($p = 0.14$, $t = 1.11$).

Table 12
Summary of Statistical Analyses of the Effectiveness of Using Low Fuming Asphalt to Reduce Worker and Area Air Standardized Exposures to Asphalt Fumes

Comparison Group/Analyte	Percent Reduction in Standardized Exposure (Conventional - Low fuming)/Conventional	p-value	t-value	Critical t at 95% confidence
Kettle Operator/TP	18.75	0.1962	1.4111	6.3137
Kettle Operator/BSF	**80.60**	**0.0403**	**7.8515**	**6.3137**
Kettle Operator/Total PAC	**84.32**	**0.0205**	**4.7886**	**2.9200**
Area Samples Around Kettle/TP	**68.18**	**0.0103**	**2.6110**	**1.7613**
Area Samples Around Kettle/BSF	**71.41**	**0.0094**	**2.6551**	**1.7613**
Area Samples Around Kettle/Total PAC	**88.51**	**0.0049**	**2.9874**	**1.7613**
Roof-Level Workers/TP	49.53	0.0610	1.6896	1.8125
Roof-Level Workers/BSF	36.31	0.0673	1.6277	1.8125
Roof-Level Workers/Total PAC	**74.61**	**0.0325**	**2.0719**	**1.8125**
Area Samples on the Roof/TP	30.65	0.1993	0.8728	1.7709
Area Samples on the Roof/BSF	-36.68	0.0560	-1.7155	1.7823
Area Samples on the Roof/Total PAC	79.72	0.1439	1.1086	1.7709

TP = total particulate
BSF = benzene soluble fraction of total particulate
PAC = polycyclic aromatic compounds

Bold = statistically significant reduction at 95% confidence level.

Comparison of Results After Adjusting Exposure Concentrations to Normal Temperature and Pressure

Normal temperature and pressure (NTP) are 77°F and 760 mmHg. The mean temperature and pressure measurement for the four days of sampling are shown in Table 13.

Table 13
Summary of Ambient Air Temperature and Pressure Measurements

Date	Number of Measurements	Mean Temperature(°F)	Mean Barometric Pressure (mm Hg)
10/5/99	4	58	740
10/6/99	4	55	735
10/7/99	4	49	735
10/8/99	4	49	735

Using the mean temperature and pressure measurements for each day, the TP, BSF, and PAC exposure results were adjusted to NTP. These data are shown in Table 14 for the kettle operator, Table 15 for the area air samples collected around the kettle, and Table 16 for the roof level workers. By adjusting to NTP data from different sites can be more readily compared.

Table 14
Kettle Operator (GP-01) NTP TP, BSF, and PAC Exposure Concentrations

Sample Date	Sample Time (min.)	NTP TP Conc. (mg/m^3)	NTP BSF Conc. (mg/m^3)	NTP Total PAC Conc. ($\mu g/m^3$)	With or Without Low Fuming Asphalt
10/5/99	278	na	na	398	Without
10/6/99	260	2.19	1.54	403	Without
10/7/99	277	1.51	<0.27	89.1	With
10/8/99	349	1.09	0.22	32.2	With

NTP = normal temperature (77°F) and pressure (760 mmHg)
TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m^3 = milligrams per cubic meter of air
$\mu g/m^3$ = micrograms per cubic meter of air
nm = nanometers
na = not available

Table 15
Area Air Sample Concentration Results For NTP TP, BSF, and PAC Collected Around the Kettle

Sample Date	Sample Location Around Kettle	Sample Time (min.)	NTP TP Conc. (mg/m³)	NTP BSF Conc. (mg/m³)	NTP Total PAC Conc. (µg/m³)	With or Without Low Fuming Asphalt
10/5/99	NE corner	255	1.17	1.07	337	Without
10/6/99	NE corner	273	4.21	3.81	601	Without
10/7/99	NE corner	302	0.48	0.50	64.0	With
10/8/99	NE corner	359	0.42	0.21	23.3	With
10/5/99	NW corner	255	1.66	1.44	890	Without
10/6/99	NW corner	273	3.65	3.06	633	Without
10/7/99	NW corner	302	0.18	0.51	15.1	With
10/8/99	NW corner	359	0.59	0.42	30.3	With
10/5/99	SE corner	254	0.28	0.18	59.4	Without
10/6/99	SE corner	273	0.67	0.50	208	Without
10/7/99	SE corner	302	0.05	0.50	23.2	With
10/8/99	SE corner	359	0.36	0.15	13.1	With
10/5/99	SW corner	250	1.29	1.19	62.7	Without
10/6/99	SW corner	273	0.72	0.50	202	Without
10/7/99	SW corner	302	0.91	0.50	145	With
10/8/99	SW corner	359	0.42	0.15	25.6	With

NTP = normal temperature (77°F) and pressure (760 mmHg)
TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m³ = milligrams per cubic meter of air
µg/m³ = micrograms per cubic meter of air
nm = nanometers

Table 16
Roof-Level Worker NTP TP, BSF, and PAC Exposure Concentrations

Sample Date	Worker ID Number	Sample Time (hr.)	NTP TP Conc. (mg/m³)	NTP BSF Conc. (mg/m³)	NTP Total PAC Conc. (µg/m³)	With or Without Low Fuming Asphalt
10/5/99	GP-02	204	1.17	0.63	2.33	Without
10/6/99	GP-02	240	1.84	0.85	267	Without
10/7/99	GP-02	236	0.64	0.23	51.3	With
10/8/99	GP-02	269	0.14	0.20	36.3	With
10/5/99	GP-03	204	0.45	0.22	308	Without
10/6/99	GP-03	240	0.59	0.28	138	Without
10/7/99	GP-03	239	0.61	0.23	98.6	With
10/8/99	GP-03	271	0.17	0.20	11.09	With
10/5/99	GP-04	212	0.44	0.22	352	Without
10/6/99	GP-04	241	0.25	0.56	98.1	Without
10/7/99	GP-04	238	0.48	0.23	68.8	With
10/8/99	GP-04	267	0.26	0.29	43.0	With

TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m³ = milligrams per cubic meter of air
µg/m³ = micrograms per cubic meter of air
nm = nanometers

Kettle Operator Personal Breathing Zone NTP Sample Results

The concentration of TP at NTP for the kettle operator when conventional asphalt was used was 2.19 mg/m³, and with low fuming asphalt, the mean at NTP was 1.30 mg/m³. The reduction in the TP concentration at NTP for the kettle operator using low fuming asphalt was 40.6%. The NTP BSF concentration for the kettle operator when conventional asphalt was used was 1.54 mg/m³, and when low fuming asphalt was used, the mean at NTP was 0.21 mg/m³. The reduction in the kettle operator's exposures between the NTP BSF concentrations when conventional asphalt was used and when low fuming asphalt was used was 86.4%. The mean

NTP total PAC concentration for the kettle operator when conventional asphalt was used was 401 μg/m^3 and when low fuming asphalt was used, the mean was 60.7 μg/m^3. The reduction in the mean total PAC concentration for the kettle operator when using low fuming asphalt was 84.9%.

NTP Area Air Sample Results For Samples Collected Around The Kettle

The mean NTP TP concentration for the four area air samples collected around the kettle when conventional asphalt was used was 1.70 mg/m^3 (SD = 1.44), and when low fuming asphalt was used the NTP concentration was 0.43 mg/m^3 (SD = 0.26) for a reduction of 74.7%. The mean NTP BSF concentration for the area air samples collected around the kettle was 1.47 mg/m^3 (SD = 1.30), and when low fuming asphalt was used the NTP concentration was 0.37 mg/m^3 (SD = 0.17) for a reduction of 74.8%. The mean NTP total PAC concentration for the area air samples collected around the kettle was 374 μg/m^3 (SD = 302), and when low fuming asphalt was used, the NTP concentration was 42.5 μg/m^3 (SD = 44.5) for a reduction of 88.6%.

Roof Level Worker Personal Breathing Zone NTP Sample Results

The mean NTP TP concentration for all roof-level workers when conventional asphalt was used was 0.79 mg/m^3 (SD = 0.60) and when low fuming asphalt was used was 0.38 mg/m^3 (SD = 0.22). The reduction in the mean NTP TP concentration for all roof-level workers using low fuming asphalt was 51.9%. The mean NTP BSF concentration for all roof-level workers when conventional asphalt was used was 0.46 mg/m^3 (SD = 0.26) and when low fuming asphalt was used was 0.23 mg/m^3 (SD = 0.03). The reduction in the mean NTP BSF concentration for all roof-level workers using low fuming asphalt was 50.0%. The mean NTP total PAC concentration for all roof-level workers when conventional asphalt was used was 194 μg/m^3 (SD = 136) and when low fuming asphalt was used was 51.5 μg/m^3 (SD = 29.9). The reduction in the mean total PAC concentration for all roof-level workers using low fuming asphalt was 73.5%.

Statistical Analysis of the Effectiveness of Using Low Fuming Asphalt to Reduce Worker and Area Air Exposures to Asphalt Fumes Adjusted to NTP

Statistical analyses were conducted on the NTP air sampling data to determine the effectiveness of reducing worker exposure to asphalt fumes by using low fuming asphalt. A summary of these analyses are shown in Table 17. Comparisons were made between air sample results for NTP TP, BSF, and total PAC while conventional asphalt was used to when low fuming asphalt was used.

Using t distribution, reductions in exposures were tested to determine if they were statistically significant at 95% confidence. The mean NTP BSF and NTP total PAC exposures for the kettle operator were found to be reduced with statistical significance at the 95% confidence level. The reductions measured in the mean NTP TP, NTP BSF, and NTP total PAC exposures for the area air samples collected around the kettle and for the roof-level workers were all found to be statistically significant at 95% confidence. Adjusting the exposure results to NTP did not alter the significance of the reductions using low fuming asphalt.

Table 17
Summary of Statistical Analyses of the Effectiveness of Using Low Fuming Asphalt to Reduce Worker and Area Air Exposures to Asphalt Fumes Adjusted to NTP

Comparison Group/Analyte	Percent Reduction in Exposure (Conventional - Low fuming)/Conventional	p-value	t-value	Critical t at 95% confidence
Kettle Operator/NTP TP	40.6	0.1237	2.4419	6.3137
Kettle Operator/NTP BSF	**86.4**	**0.0049**	**64.672**	**6.3137**
Kettle Operator/NTP Total PAC	**84.9**	**0.0035**	**11.876**	**2.9200**
Area Samples Around Kettle/NTP TP	**74.7**	**0.0135**	**2.4682**	**1.7613**
Area Samples Around Kettle/NTP BSF	**74.8**	**0.0162**	**2.3731**	**1.7613**
Area Samples Around Kettle/NTP Total PAC	**88.6**	**0.0041**	**3.0711**	**1.7613**
Roof-Level Workers/NTP TP	51.9	0.0756	1.5541	1.8125
Roof-Level Workers/NTP BSF	**50.0**	**0.0258**	**2.2088**	**1.8125**
Roof-Level Workers/NTP Total PAC	**73.5**	**0.0154**	**2.5126**	**1.8125**

TP = total particulate
BSF = benzene soluble fraction of total particulate
PAC = polycyclic aromatic compounds

Bold = statistically significant reduction at 95% confidence level.

Comparison of Results by Standardizing Exposure Concentrations by the Amount of Asphalt Used and Adjusted to NTP

The NTP exposure concentrations listed in Tables 14, 15, and 16 standardized by dividing the NTP exposure concentrations by the amount of asphalt used that day. These NTP standardized exposure concentrations are listed in Tables 18, 19, and 20 for the kettle operator, area air samples collected around the kettle, and the roof level workers, respectively.

Table 18
Kettle Operator (GP-01) NTP Standardized TP, BSF, and PAC Exposure Concentrations

Sample Date	Sample Time (min.)	NTP Standardized TP Conc. (mg/m³lb)	NTP Standardized BSF Conc. (mg/m³lb)	NTP Standardized Total PAC Conc. (µg/m³lb)	With or Without Low Fuming Asphalt
10/5/99	278	na	na	0.15293	Without
10/6/99	260	0.00061	0.00043	0.11205	Without
10/7/99	277	0.00050	0.00006	0.02971	With
10/8/99	349	0.00061	0.00012	0.01789	With

NTP = normal temperature (77°F) and pressure (760 mmHg)
TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m^3lb = milligrams per cubic meter of air times pounds of asphalt
$\mu g/m^3lb$ = micrograms per cubic meter of air times pounds of asphalt
nm = nanometers
na = not available

Table 19
Area Air Sample Concentration Results for NTP Standardized TP, BSF, and PAC Collected Around the Kettle

Sample Date	Sample Location Around Kettle	Sample Time (min.)	NTP Standardized TP Conc. (mg/m³lb)	NTP Standardized BSF Conc. (mg/m³lb)	NTP Standardized Total PAC Conc. (μg/m³lb)	With or Without Low Fuming Asphalt
10/5/99	NE corner	255	0.00045	0.00041	0.12985	Without
10/6/99	NE corner	273	0.00117	0.00106	0.16703	Without
10/7/99	NE corner	302	0.00016	0.00017	0.02135	With
10/8/99	NE corner	359	0.00024	0.00012	0.01293	With
10/5/99	NW corner	255	0.00063	0.00055	0.34234	Without
10/6/99	NW corner	273	0.00101	0.00085	0.17585	Without
10/7/99	NW corner	302	0.00006	0.00017	0.00502	With
10/8/99	NW corner	359	0.00033	0.00024	0.01685	With
10/5/99	SE corner	254	0.00011	0.00007	0.02284	Without
10/6/99	SE corner	273	0.00019	0.00014	0.05773	Without
10/7/99	SE corner	302	0.00002	0.00017	0.00772	With
10/8/99	SE corner	359	0.00020	0.00008	0.00728	With
10/5/99	SW corner	250	0.00050	0.00046	0.02411	Without
10/6/99	SW corner	273	0.00020	0.00014	0.05609	Without
10/7/99	SW corner	302	0.00030	0.00017	0.04847	With
10/8/99	SW corner	359	0.00024	0.00008	0.01422	With

NTP = normal temperature (77°F) and pressure (760 mmHg)
TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m³lb = milligrams per cubic meter of air times pounds of asphalt
μg/m³ = micrograms per cubic meter of air times pounds of asphalt
nm = nanometers

Table 20
Roof-Level Worker NTP TP, BSF, and PAC Exposure Concentrations

Sample Date	Worker ID Number	Sample Time (hr.)	NTP Standardized TP Conc. (mg/m³)	NTP Standardized BSF Conc. (mg/m³)	NTP Standardized Total PAC Conc. (µg/m³)	With or Without Low Fuming Asphalt
10/5/99	GP-02	204	0.00045	0.00024	0.11832	Without
10/6/99	GP-02	240	0.00051	0.00024	0.07407	Without
10/7/99	GP-02	236	0.00021	0.00008	0.01709	With
10/8/99	GP-02	269	0.00008	0.00011	0.02016	With
10/5/99	GP-03	204	0.00017	0.00009	0.13531	Without
10/6/99	GP-03	240	0.00017	0.00008	0.03835	Without
10/7/99	GP-03	239	0.00020	0.00008	0.03287	With
10/8/99	GP-03	271	0.00009	0.00011	0.00619	With
10/5/99	GP-04	212	0.00017	0.00009	0.13531	Without
10/6/99	GP-04	241	0.00007	0.00016	0.02724	Without
10/7/99	GP-04	238	0.00016	0.00008	0.02292	With
10/8/99	GP-04	267	0.00014	0.00016	0.02386	With

TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
360 PAC = PAC measured at 360 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 360 and 400 nm PAC concentrations
mg/m³ = milligrams per cubic meter of air
µg/m³ = micrograms per cubic meter of air
nm = nanometers

Statistical Analysis of the Effectiveness of Using Low Fuming Asphalt to Reduce Worker and Area Air NTP Standardized Exposures to Asphalt Fumes

Statistical analysis of the NTP standardized exposure concentrations was conducted in the same manner as exposure concentrations. Statistical comparisons were done for the kettle operator (GP-01), the combined results for the three roof-level workers (GP-02, -03, and -04), and the combined results for the four area air samples collected around the kettle. These statistical analyses are listed in Table 21. Shown in Table 21, for each comparison group and each analyte was the percent reduction in the mean exposure concentration when comparing mean NTP standardized exposure while using conventional asphalt to mean NTP standardized exposures while using low fuming asphalt, the p- and t-values for the reductions, and the critical t-values at 95% confidence.

Statistical comparison of the kettle operator's (GP-01) mean NTP standardized TP concentration with conventional asphalt to the mean NTP standardized TP concentration with low fuming asphalt was a reduction of 8.87% ($p = 0.33$, $t = 0.61$). The reduction in mean NTP standardized BSF concentration was 78.3% when using low fuming asphalt compared to conventional asphalt, which was statistically significant at 95% confidence ($p = 0.05$, $t = 6.85$). The reduction in mean NTP standardized total PAC concentration using low fuming asphalt was 82.0% which was statistically significant at 95% confidence ($p = 0.02$, $t = 5.11$).

The reduction in the mean NTP standardized TP concentration for the four area air samples collected around the kettle when using low fuming asphalt was 63.7%, which is statistically significant at 95% confidence ($p = 0.02$, $t = 2.37$). The reduction in the mean NTP standardized BSF concentration for all the area air samples collected around the kettle when using low fuming asphalt was 67.5%, which was statistically significant at 95% confidence ($p = 0.01$, $t = 2.44$). The reduction in the mean NTP standardized total PAC concentration for all the area air samples collected around the kettle when using low fuming asphalt was 86.3%, which was statistically significant at 95% confidence ($p = 0.008$, $t = 2.74$).

Combining the NTP standardized personal breathing zone air sample results for the three roof-level workers, their mean NTP standardized TP concentration was reduced by 41.8% when using low fuming asphalt ($p = 0.10$, $t = 1.40$). The combined results show that the three roof-level workers' mean NTP standardized BSF concentration was reduced by 31.8% when using low fuming asphalt ($p = 0.10$, $t = 1.36$). The combined roof-level workers' mean NTP standardized total PAC concentration was reduced by 68.8% when using low fuming asphalt, which was statistically significant at 95% confidence ($p = 0.03$, $t = 2.05$).

Table 21
Summary of Statistical Analyses of the Effectiveness of Using Low Fuming Asphalt to Reduce Worker and Area Air NTP Standardized Exposures to Asphalt Fumes

Comparison Group/Analyte	Percent Reduction in Standardized Exposure (Conventional - Low fuming)/Conventional	p-value	t-value	Critical t at 95% confidence
Kettle Operator/TP	8.87	0.3260	0.6084	6.3137
Kettle Operator/BSF	**78.3**	**0.0462**	**6.8483**	**6.3137**
Kettle Operator/Total PAC	**82.0**	**0.0181**	**5.1086**	**2.9200**
Area Samples Around Kettle/TP	**63.7**	**0.0164**	**2.3682**	**1.7613**
Area Samples Around Kettle/BSF	**67.5**	**0.0142**	**2.4433**	**1.7613**
Area Samples Around Kettle/Total PAC	**86.3**	**0.0080**	**2.7374**	**1.7613**
Roof-Level Workers/TP	41.8	0.0953	1.4041	1.8125
Roof-Level Workers/BSF	31.8	0.1011	1.3649	1.8125
Roof-Level Workers/Total PAC	**68.8**	**0.0334**	**2.0554**	**1.8125**

TP = total particulate
BSF = benzene soluble fraction of total particulate
PAC = polycyclic aromatic compounds

Bold = statistically significant reduction at 95% confidence level.

DISCUSSION

The highest exposures to TP, BSF, and total PAC were measured on the kettle operator and area air samples collected around the kettle while using conventional asphalt. The kettle operator's exposure to TP, BSF, and total PAC were all reduced when using low fuming asphalt compared to conventional asphalt. Reductions in exposures of 47%, 88%, 87% for TP, BSF, and total PAC, respectively, were measured for the kettle operator. The reductions measured for BSF and total PAC exposures were statistically significant at 95% confidence. Similarly, the mean exposure concentrations for the four area air samples collected around the kettle had reductions of 78%, 78%, and 90% in TP, BSF, and total PAC exposures when using low fuming asphalt compared to exposures measured while using conventional asphalt. These reductions were all statistically significant at 95% confidence.

The kettle operator's standardized exposure to TP, BSF, and total PAC also were all reduced when using low fuming asphalt compared to his exposures while using conventional asphalt.

Reductions in standardized exposures of 19%, 81%, and 84% for TP, BSF, and total PAC, respectively, were measured for the kettle operator. For each analyte, the reduction in standardized exposures was less than their counterpart in the measured exposures. The reductions measured for standardized BSF and total PAC exposures were statistically significant at 95% confidence. Similarly, the combination of the four area air samples standardized exposure concentrations collected around the kettle had reductions of 68%, 71%, and 88% in standardized TP, BSF, and total PAC exposures when using low fuming asphalt compared to exposures measured while using conventional asphalt. These reductions were all statistically significant at 95% confidence for TP, BSF, and total PAC. The measured exposure reductions were also significant at 95% confidence.

Reductions in standardized TP, BSF, and total PAC exposures when using low fuming asphalt compared to using conventional asphalt were also determined for the three roof-level workers. The reductions measured in the roof-level workers' standardized exposures to TP, BSF, and total PAC were 50%, 36%, and 75%, respectively. The reductions measured in the roof-level standardized exposures to TP and BSF were not statistically significant at 95% confidence. The reduction measured in the roof-level workers' standardized exposure to total PAC was statistically significant at 95% confidence just like the measured exposure.

The combination of the area air samples collected around the work area on the roof had reductions of 46%, -0.37%, and 82% in TP, BSF, and total PAC exposures when using low fuming asphalt compared to exposures measured while using conventional asphalt. None of these reductions were statistically significant at 95% confidence. The combination of the standardized area air sample exposures collected around the work area on the roof had reductions of 31%, -37%, and 80% in TP, BSF, and total PAC exposures when using low fuming asphalt compared to exposures measured while using conventional asphalt. None of these standardized exposure reductions were statistically significant at 95% confidence, just like the measured exposure reductions.

When the exposure concentrations were adjusted to NTP as shown in Tables 14, 15, and 16, the reduction in exposures while using low fuming asphalt were only slightly less than those reductions seen for the measured exposures. All reductions that were statistically significant in the measured exposure concentrations remained statistically significant when the concentrations were adjusted to NTP.

When the NTP exposure concentrations were standardized by dividing the concentrations by the amount of asphalt used that day as shown in Tables 18, 19, and 20, the reductions in exposure measured when using low fuming asphalt were less than those calculated for the standardized exposure concentrations. Those reductions in standardized exposures measured while low fuming asphalt was used that were statistically significant remained statistically significant when they were NTP standardized exposure concentrations.

Examination of the air sampling data shows that the reductions seen in both the personal breathing zone and area air samples were greater for the organic results (BSF and total PAC) than for TP, indicating that using low fuming asphalt may provide even greater protection from organic materials being emitted from the kettle than inert materials.

CONCLUSIONS

The results from this survey strongly suggest that both worker and area air exposures to TP, BSF, and total PAC were reduced when using low fuming asphalt when compared to conventional asphalt. Reductions were seen for TP, BSF, and total PAC for personal breathing zone samples for the kettle operator and for area air samples collected around the kettle and were for the most part statistically significant at 95% confidence. This was also true when the exposure data was standardized by the amount of asphalt used each day, when the data was adjusted to NTP, and when the data was adjusted to NTP and standardized. The results also show that the reduction is even greater for organic compounds (both BSF and PAC results) when compared to TP results. Reductions seen for TP, BSF, and total PAC for personal breathing zone samples for the roof-level workers were statistically significant at 95% confidence, but that was not the case for the reductions for the standardized exposure, NTP exposure, or NTP standardized exposure to TP and BSF. This would seem to indicate that the amount of asphalt used on a given day affects the degree of exposure for the roof-level workers. The major limitation of this study is the fact that only two days of sampling were conducted when conventional asphalt was used and two days of sampling were conducted when low fuming asphalt was used. Additional studies are needed to verify the trends seen here.

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