SURVEY REPORT,

CONTROL TECHNOLOGY EVALUATION FOR CONTROLLING WORKER EXPOSURE TO ASPHALT FUMES FROM ROOFING KETTLES: KETTLE OPERATED USING AN AFTERBURNER SYSTEM

at

Tampa Bay Technical High School
6410 Orient Rd
Tampa, Florida 33610

and

West Park Village at West Chase
10050 Montague St
Tampa, Florida 33626

REPORT WRITTEN BY
David A Marlow
Jennifer L Topmiller

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U S Department of Health and Human Services
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Division of Applied Research and Technology
4676 Columbia Parkway, Mail stop R5
Cincinnati, Ohio 45226

FACILITIES SURVEYED	Tampa Bay Technical School 6410 Orient Rd Tampa, FL 33610 West Park Village at West Chase 10050 Montague St Tampa, FL 33626
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SURVEY DATES	September 11 through 13, 2001
SURVEY CONDUCTED BY	David A Marlow Dan Farwick
FACILITY REPRESENTATIVE	No facility representative available
CONTRACTOR	Quality Roofing of Florida, Inc 6601 North 50th St Tampa, Florida 33610 813-620-4797
EMPLOYEE REPRESENTATIVE	No representatives
ANALYTICAL WORK PERFORMED BY	DataChem Laboratories 960 West LeVoy Drive Salt Lake City, Utah 84123-2547

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SUMMARY

On September 11 through 13, 2001, two field surveys were conducted at sites where built up asphalt roofs were being installed One survey was conducted at Tampa Bay Technical High School in Tampa, Florida where cap sheet was being installed on top of a recently installed built up asphalt roof The other survey was conducted at West Park Village at West Chast in Tampa, Florida, a construction site where a built up asphalt roof was being installed on a new apartment/business building The surveys were conducted to evaluate the effectiveness of an afterburner system with a safety loading door on an asphalt kettle to reduce worker exposure to asphalt fumes The kettle used at the Tampa Bay Technical High School was equipped with an afterburner system and safety loading door, and all of the asphalt was added through the safety loading door The kettle used at the West Park Village was not equipped with any engineering controls to reduce asphalt fume emission, and the kettle lid remained open the entire work day

Personal breathing zone and area air samples were collected and analyzed for total particulate (TP), benzene soluble fraction (BSF) of the TP, and total polycyclic aromatic compounds (PAC) These three analyses were chosen to represent indices of exposure to asphalt fumes Air samples were collected on the kettle operator and two roof level workers, area air samples were collected around the four corners of the kettle

The kettle operator's exposures at the Tampa Bay Technical High School to TP, BSF, and total PAC were all less than the exposures measured for the kettle operator at West Park Village The percent differences between the two kettle operators' exposures to TP, BSF, and total PAC were 94%, 97%, and 91%, respectively Percent differences of 97%, 98%, and 98% in TP, BSF, and total PAC were measured for the area air samples collected around the two kettles For the roof level workers, exposures to TP, BSF, and total PAC were 28%, 10%, and 48% higher for the workers at the Tampa Bay Technical High School when compared to the workers at the West Park Village The percent differences in exposures for the kettle operators and the area air samples collected around the kettle were all statistically significant ($p \leq 0.05$)

The asphalt fume concentrations measured for the kettle operator and the area samples collected around the kettle were all significantly lower at the site where the control was in use than at the site with no control The major limitation on these findings is that the comparison was made between different sites using two different types of kettles The differences in exposures seen between the two sites for the kettle operators and the area air samples collected around the kettle were not seen when comparing the roof level workers Exposures were higher for the roof level workers at the Tampa Bay Technical High School

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

Based on 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 where asphalt is used 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 1999, an estimated 50,000 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 [17] Studying ways to reduce exposure to these construction workers addresses the Healthy People 2000 Objectives, the NIOSH National Occupational Research Agenda (NORA), and OSHA priorities [18-20]

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[21] 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 Thermal Properties 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

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 [22] 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 [23] 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 [24] 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 [25] 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,[26] asphalt fumes should be considered a potential occupational carcinogen [27] This recommendation was based on

information presented in the Niemeier et al study[28] This NIOSH conclusion is based on the collective evidence found in available health effects and exposure data[17]
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

STUDY BACKGROUND

Two surveys were conducted September 11 through 13, 2001 One was at Tampa Bay Technical High School where a two ply BUR was being applied on an existing roof The second was at West Park Village at West Chast where a three ply BUR was being applied to a new apartment and business building that was under construction The engineering control used at the high school was a Reeves afterburner system, no engineering controls were used at the new apartment and business building construction site 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

SITE DESCRIPTION AND WORK ACTIVITY

Two sites were surveyed at the same time for three days One site was at a high school, Tampa Bay Technical High School, where a mineral fiberglass cap sheet was being added to a newly replaced BUR The kettle used at this site was a 650 gallon Reeves kettle with an afterburner/safety loading door system The afterburner was in operation the entire time and all the asphalt added to the kettle was added using the safety loading door for the three days sampled The other site surveyed was at a new construction site A three ply BUR was being installed on a new apartment/business building, West Park Village at West Chase The kettle used at this site was a 400 gallon Blackwell kettle which had no engineering controls and was operated each day with the lid open The amount of asphalt used each day at each site is shown in Table 2

Table 2 Amount of Asphalt Used Each Day		
Date	Tampa Bay Tech HS (pounds)	West Park Village (pounds)
09/11/01	900	600
09/12/01	1430	400
09/13/01	400	500

The roofers at the Tampa Bay Technical high school site began work at 8 00 a m each day At that time, the kettle operator loaded asphalt into a 650 gallon kettle manufactured by Reeves and equipped with two afterburners, and lit the propane burners to bring the asphalt up to the correct temperature All asphalt added to the kettle was added through the safety loading door The high school was made up of multiple wings The kettle was located at ground level in front of the wing where the cap sheet was being installed During the three days that the survey was conducted, the roofers worked on wings installing the cap sheet where 2-ply of asphalt and felt had been applied to insulation board

The roofer at the West Park Village site also began worker at 8 00 am each day At that time, the kettle operator loaded asphalt into a 400 gallon kettle manufactured by Blackwell and lit the propane burners to bring the asphalt up to the correct temperature The Blackwell kettle had no engineering controls on it, and the kettle lid remained open during operation The West Park Village apartment/business building was four stories The kettle was located at ground level in the back of the building in a parking lot During the three days that the survey was conducted, the roofers applied two plies of asphalt and felt on top of insulation board followed by a mineral fiberglass cap sheet

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 the afterburner operating and the safety loading kettle lid open and closed 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 a 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)

Kettle Temperature

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

Summarized in Table 3A for the three days of sampling at the Tampa Bay Technical High School are the mean kettle temperature measurements along with the mean kettle gauge temperature measurements Table 3B summarizes the same information for the West Park Village site

Table 3A Summary of Kettle Temperature Data Tampa Bay Technical High School					
Date	Number of Measurements	Mean Kettle Temperature (°F)	Minimum Kettle Temperature (°F)	Maximum Kettle Temperature (°F)	Mean Gauge Kettle Temperature (°F)
09/11/2001	2	553	532	574	531
09/12/2001	2	495	443	546	560
9/13/2001	0	---	----	---	548

Table 3B Summary of Kettle Temperature Data West Park Village at West Chase					
Date	Number of Measurements	Mean Kettle Temperature (°F)	Minimum Kettle Temperature (°F)	Maximum Kettle Temperature (°F)	Mean Gauge Kettle Temperature (°F)
09/11/2001	1	400	400	400	426
09/12/2001	10	531	403	563	404
9/13/2001	12	565	507	612	437

Statistical Evaluation

Personal breathing zone and area air sample data for TP, BSF, and total PAC were statistically compared under two conditions afterburners on, the kettle lid closed (Tampa Bay Technical High School) and no afterburners, kettle lid open (West Park Village at West Chase) Student's t-test was used Statistical comparisons were also completed for the personal breathing zone and area air sampling data adjusted to normal temperature and pressure (NTP)

RESULTS

Kettle Operator Personal Breathing Zone Sample Results

Personal breathing zone air samples were collected on the kettle operator at the high school site and at the West Park Village site and analyzed for TP, BSF, and total PAC Samples were collected for three days, and the results are listed in Table 4A for the Tampa Bay Technical high school site and in Table 4B for the West Park Village site and summarized in Table 5 During the three days of sampling at the high school, the kettle lid equipped with two afterburners and safety loading doors was operated with the afterburner on and kettle lid closed using the safety loading doors to add asphalt to the kettle During the three days of sampling at the West Park Village building, the kettle lid was open the entire day of work

Table 4A Kettle Operator Exposure Concentrations
Tampa Bay Technical High School

Sample Date	Sample Time (min)	TP Conc (mg/m³)	BSF Conc (mg/m³)	370 PAC Conc (μg/m³)	400 PAC Conc (μg/m³)	Total PAC Conc (μg/m³)	Kettle Conditions
09/11/2001	503	0 26	0 22	na	na	na	afterburner on, lid closed
09/12/2001	508	0 24	0 05	10 0	1 95	12 0	afterburner on, lid closed
09/13/2001	356	0 18	0 03	39 3	16 9	56 2	afterburner on, lid closed

For all tables
TP = total particulate
BSF = benzene soluble fraction of TP
PAC = polycyclic aromatic compounds
370 PAC = PAC measured at 370 nm emission wavelength
400 PAC = PAC measured at 400 nm emission wavelength
Total PAC = sum of 370 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 4B Kettle Operator Exposure Concentrations West Park Village at West Chase							
Sample Date	Sample Time (min)	TP Conc (mg/m^3)	BSF Conc (mg/m^3)	370 PAC Conc ($\mu g/m^3$)	400 PAC Conc ($\mu g/m^3$)	Total PAC Conc ($\mu g/m^3$)	Kettle Conditions
09/11/2001	448	4 10	4 30	209	37 4	246	no afterburner, lid open
09/12/2001	305	2 09	1 89	209	35 3	244	no afterburner, lid open
09/13/2001	307	5 31	5 60	615	122	737	no afterburner, lid open

Table 5 Summary of the Kettle Operators' Exposure Results Tampa Bay Technical High School and West Park Village at West Chase			
	Mean Concentration		% Difference
Exposure Analyte	afterburner on/lid closed	no afterburner/ lid open	afterburner on/lid closed vs no afterburner/ lid open
TP (mg/m^3)	0 23	3 83	94 1
BSF (mg/m^3)	0 10	3 93	97 5
Total PAC ($\mu g/m^3$)	34 1	409	91 7

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 at both the high school and at the office building sites Samples were collected and analyzed for TP, BSF, and PAC During the three days of sampling, the area air samples were collected at the high school with the afterburner on and the kettle lid closed At the West Park Village site there was no engineering control, and the kettle lid was left open throughout the work day The results for the samples collected at the high school are shown in Table 6A and for the West Park Village site in Table 6B These results are summarized in Table 7

Table 6A Area Air Sample Concentration Results Collected Around the Kettle Tampa Bay Technical High School								
Sample Date	Sample Location Around Kettle	Sample Time (min)	TP Conc (mg/m^3)	BSF Conc (mg/m^3)	370 PAC Conc (μg/m^3)	400 PAC Conc (μg/m^3)	Total PAC Conc (μg/m^3)	Kettle Conditions
09/11/2001	NE corner	492	<0 04	0 01	1 05	0 71	1 75	afterburner on, lid closed
09/11/2001	NW corner	496	0 01	0 01	3 06	0 71	3 78	afterburner on, lid closed
09/11/2001	SE corner	278	0 22	0 28	10 7	2 14	12 9	afterburner on, lid closed
09/11/2001	SW corner	502	0 59	0 63	na	na	na	afterburner on, lid closed
09/12/2001	NE corner	479	0 11	<0 06	3 55	0 77	4 32	afterburner on, lid closed
09/12/2001	NW corner	483	0 14	0 05	8 51	1 66	10 2	afterburner on, lid closed
09/12/2001	SE corner	481	0 01	<0 06	0 15	0 52	0 67	afterburner on, lid closed
09/12/2001	SW corner	479	0 07	<0 06	na	na	na	afterburner on, lid closed
09/13/2001	NE corner	354	0 14	na	19 7	4 37	24 1	afterburner on, lid closed
09/13/2001	NW corner	353	0 04	<0 07	11 4	2 68	14 1	afterburner on, lid closed
09/13/2001	SE corner	354	<0 06	<0 07	6 65	2 12	8 77	afterburner on, lid closed
09/13/2001	SW corner	166	0 14	<0 07	25 1	6 27	31 4	afterburner on, lid closed

Table 6B Area Air Sample Concentration Results Collected Around the Kettle West Park Village at West Chase								
Sample Date	Sample Location Around Kettle	Sample Time (min)	TP Conc (mg/m^3)	BSF Conc (mg/m^3)	370 PAC Conc (μg/m^3)	400 PAC Conc (μg/m^3)	Total PAC Conc (μg/m^3)	Kettle Conditions
09/11/2001	NE corner	491	7 51	8 30	1177	212	1389	no afterburner, lid open
09/11/2001	NW corner	492	4 23	4 82	223	41 7	265	no afterburner, lid open
09/11/2001	SE corner	494	5 06	5 25	525	87 5	612	no afterburner, lid open
09/11/2001	SW corner	493	4 12	4 50	417	72 5	490	no afterburner, lid open
09/12/2001	NE corner	351	3 37	3 63	342	61 3	404	no afterburner, lid open
09/12/2001	NW corner	348	3 69	3 95	137	23 1	160	no afterburner, lid open

Table 6B Area Air Sample Concentration Results Collected Around the Kettle West Park Village at West Chase								
Sample Date	Sample Location Around Kettle	Sample Time (min)	TP Conc (mg/m^3)	BSF Conc (mg/m^3)	370 PAC Conc (μg/m^3)	400 PAC Conc (μg/m^3)	Total PAC Conc (μg/m^3)	Kettle Conditions
09/12/2001	SE corner	349	3 02	2 40	327	56 9	384	no afterburner, lid open
09/12/2001	SW corner	348	3 40	3 51	303	47 7	351	no afterburner, lid open
09/13/2001	NE corner	385	1 68	1 65	194	36 3	231	no afterburner, lid open
09/13/2001	NW corner	382	3 75	3 99	na	na	na	no afterburner, lid open
09/13/2001	SE corner	148	13 5	13 8	na	na	na	no afterburner, lid open
09/13/2001	SW corner	391	2 90	3 13	390	71 5	461	no afterburner, lid open

Table 7 Summary of the Area Air Samples Collected Around the Kettle Tampa Bay Technical High School and West Park Village at West Chase			
Exposure Analyte	Mean Concentration		% Difference afterburner on/lid closed vs no afterburner/ lid open
	afterburner on/lid closed	no afterburner/ lid open	
TP (mg/m^3)	0 12	4 69	97 3
BSF (mg/m^3)	0 10	4 91	97 9
Total PAC (μg/m^3)	11 3	475	97 6

Roof Level Worker Personal Breathing Zone Sample Results

Personal breathing zone air samples were collected on the roof level workers at both the Tampa Bay Technical High School and West Park Village. Two workers at both sites, one who was mopping and one lugging asphalt, were sampled for TP, BSF, and total PAC for three days. During the three days of sampling at the high school, the kettle equipped with two afterburners and safety loading doors was used with the afterburners on and kettle lid closed. These sample results are shown in Table 8A and summarized in Table 9. During the three days of sampling at West Park Village site, no engineering controls were used, and the kettle lid was kept open during the entire work shift. These sample results are shown in Table 8B and summarized in Table 9.

Table 8A Roof-Level Workers' Exposure Concentrations
Tampa Bay Technical High School

Sample Date	Worker ID Number	Sample Time (min.)	TP Conc (mg/m^3)	BSF Conc (mg/m^3)	370 PAC Conc ($\mu g/m^3$)	400 PAC Conc ($\mu g/m^3$)	Total PAC Conc ($\mu g/m^3$)	Kettle Conditions
09/11/2001	*MP-02*	434	0.69	0.57	na	na	na	afterburner on, lid closed
0912/2001	MP-02	317	0.38	0.30	56.7	8.82	65.6	afterburner on, lid closed
09/13/2001	MP-02	208	<0.10	<0.11	67.7	12.6	80.3	afterburner on, lid closed
09/11/2001	MP-03	440	0.37	0.36	62.8	12.1	74.9	afterburner on, lid closed
09/12/2001	MP-03	316	0.88	0.82	114	21.1	135	afterburner on, lid closed
0913/2001	MP-03	206	0.35	0.37	48.1	9.14	57.2	afterburner on, lid closed

Table 8B. Roof-Level Workers' PAC Exposure Concentrations West Park Village at West Chase								
Sample Date	Worker ID Number	Sample Time (min)	TP Conc (mg/m³)	BSF Conc (mg/m³)	370 PAC Conc (µg/m³)	400 PAC Conc (µg/m³)	Total PAC Conc (µg/m³)	Kettle Conditions
09/11/2001	MP-05	414	0 77	0 85	88 7	14 8	104	no afterburner, lid open
0912/2001	MP-05	288	<0 07	<0 08	23 0	3 84	26 9	no afterburner, lid open
09/13/2001	MP-05	369	0 43	0 38	42 1	8 15	50 3	no afterburner, lid open
09/11/2001	MP-06	407	<0 04	<0 06	na	na	na	no afterburner, lid open
09/12/2001	MP-06	317	0 24	0 40	25 8	4 35	30 2	no afterburner, lid open
0913/2001	MP-06	377	0 55	0 51	55 6	9 93	65 5	no afterburner, lid open

Table 9 Summary of the Roof level Workers' Exposure Results Tampa Bay Technical High School and West Park Village at West Chase			
Exposure Analyte	Mean Concentration		% Difference afterburner on/lid closed vs no afterburner/ lid open
	afterburner on/lid closed	no afterburner/ lid open	
TP (mg/m³)	0 45	0 34	-33 8
BSF (mg/m³)	0 41	0 37	-9 23
Total PAC (µg/m³)	82 6	55 3	-49 4

Statistical Analysis of the Effectiveness of Using an Afterburner System with a Safety Loading Door 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 an afterburner system with a safety loading door A summary of these analyses is shown in Table 10 Comparisons were made between air sample results for TP, BSF, and total PAC at a site with a kettle with no afterburner/safety loading door system and the kettle lid open to a site with an afterburner/safety loading door system with the afterburner on and the kettle lid closed Comparisons were made for the following groups the kettle operator, the four area air samples collected around the asphalt kettle, and the roof-level workers Included in Table 10 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

Using t distribution, reductions in exposures were tested to determine if they were statistically significant at 95% confidence

Table 10. Summary of Statistical Analyses

Comparison Group/Analyte	Afterburner/ Kettle lid Condition	Percent Difference in Exposure	p-value	t-value	Critical t at 95% confidence
Kettle Operator/TP	on/lid closed vs off/open	**94 1**	0 009	**3 85**	2 13
Kettle Operator/BSF	on/lid closed vs off/open	**97 5**	0 012	**3 53**	2 13
Kettle Operator/Total PAC	on/lid closed vs off/open	91 7	0 088	1 77	2 35
Area Samples Around Kettle/TP	on/lid closed vs off/open	**97 3**	0 00004	**4 84**	1 72
Area Samples Around Kettle/BSF	on/lid closed vs off/open	**97 9**	0 00008	**4 65**	1 72
Area Samples Around Kettle/Total PAC	on/lid closed vs off/open	**97 6**	0 0002	**4 22**	1 73
Roof-Level Workers/TP	on/lid closed vs off/open	-33 8	0 266	-0 65	1 81
Roof-Level Workers/BSF	on/lid closed vs off/open	-9 23	0 419	-0 21	1 81
Roof-Level Workers/Total PAC	on/lid closed vs off/open	-49 4	0 010	-1 40	1 86

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 (25°F) and 29 92 in Hg (760 mmHg) The ambient air temperature and pressure measurement for the two days of sampling at the high school site and apartment/business site are shown in Tables 11A and 11B, respectively

Table 11A Mean Ambient Air Temperature and Pressure Measurements Tampa Bay Technical High School			
Date	Number of Measurements	Mean Ambient Air Temperature (°F)	Mean Barometric Pressure (in Hg)
09/11/2001	11	87 8	30 00
09/12/2001	8	88 7	29 96
09/13/2001	6	77 5	29 84

Table 11B Mean Ambient Air Temperature and Pressure Measurements West Park Village at West Chase			
Date	Number of Measurements	Mean Ambient Air Temperature (°F)	Mean Barometric Pressure (in Hg)
09/11/2001	16	87 5	29 96
09/12/2001	11	83 8	29 96
09/13/2001	12	80 8	29 88

Using the temperature and pressure measurements for the time of the day the sample was collected, the TP, BSF, and PAC exposure results were adjusted to NTP These data are shown in Table 12A and B and summarized in Table 13 for the kettle operators, Table 14A and B and summarized in Table 15 for the area air samples collected around the kettles, and Table 16A and B and summarized in Table 17 for the roof level workers By adjusting to NTP, data from different sites can be more readily compared

Table 12A Kettle Operator NTP Exposure Concentrations Tampa Bay Technical High School				
Sample Date	NTP TP Conc (mg/m³)	NTP BSF Conc (mg/m³)	NTP Total PAC Conc (µg/m³)	Kettle Conditions
09/11/2001	0 25	0 22	na	afterburner on/lid closed
09/12/2001	0 23	0 05	11 8	afterburner on/lid closed
09/13/2001	0 18	0 03	56 0	afterburner on/lid closed

For all tables NTP = normal temperature (77°F) and pressure (29 92 in Hg)

Table 12B Kettle Operator NTP Exposure Concentrations West Park Village at West Chase				
Sample Date	NTP TP Conc (mg/m³)	NTP BSF Conc (mg/m³)	NTP Total PAC Conc (µg/m³)	Kettle Conditions
09/11/2001	3 61	3 79	217	no afterburner/lid open
09/12/2001	1 92	1 74	224	no afterburner/lid open
09/13/2001	5 05	5 33	701	no afterburner/lid open

Table 13 Summary of the Kettle Operators' NTP Exposure Results Tampa Bay Technical High School and West Park Village at West Chase			
Exposure Analyte	Mean Concentration		% Difference afterburner on/lid closed vs no afterburner/ lid open
	afterburner on/ lid closed	no afterburner/ lid open	
NTP TP (mg/m³)	0 22	3 53	93 7
NTP BSF (mg/m³)	0 10	3 62	97 3
NTP Total PAC (µg/m³)	33 9	381	91 1

Table 14A Area Air Sample NTP Concentration Results Collected Around the Kettle Tampa Bay Technical High School						
Sample Date	Sample Location Around Kettle	Sample Time (min)	NTP TP Conc (mg/m^3)	NTP BSF Conc (mg/m^3)	NTP Total PAC Conc (μg/m^3)	Kettle Conditions
09/11/2001	NE corner	492	<0 04	0 01	1 75	afterburner on, lid closed
09/11/2001	NW corner	496	0 01	0 01	3 71	afterburner on, lid closed
09/11/2001	SE corner	278	0 22	0 28	12 6	afterburner on, lid closed
09/11/2001	SW corner	502	0 58	0 62	Na	afterburner on, lid closed
09/12/2001	NE corner	479	0 11	<0 04	4 24	afterburner on, lid closed
09/12/2001	NW corner	483	0 14	0 05	9 99	afterburner on, lid closed
09/12/2001	SE corner	481	0 01	<0 04	0 65	afterburner on, lid closed
09/12/2001	SW corner	479	0 07	<0 04	Na	afterburner on, lid closed
09/13/2001	NE corner	354	0 14	na	24 0	afterburner on, lid closed
09/13/2001	NW corner	353	0 04	<0 07	14 1	afterburner on, lid closed
09/13/2001	SE corner	354	<0 06	<0 07	8 74	afterburner on, lid closed
09/13/2001	SW corner	166	na	na	31 3	afterburner on, lid closed

Table 14B. Area Air Sample NTP Concentration Results Collected Around the Kettle West Park Village at West Chase						
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)	Kettle Conditions
09/11/2001	NE corner	491	6 62	7 32	1224	no afterburner, lid open
09/11/2001	NW corner	492	3 73	4 25	234	no afterburner, lid open
09/11/2001	SE corner	494	4 46	4 63	539	no afterburner, lid open
09/11/2001	SW corner	493	3 63	3 97	432	no afterburner, lid open
09/12/2001	NE corner	351	3 10	3 34	371	no afterburner, lid open
09/12/2001	NW corner	348	3 40	3 64	147	no afterburner, lid open
09/12/2001	SE corner	349	2 77	2 21	353	no afterburner, lid open
09/12/2001	SW corner	348	3 12	3 23	323	no afterburner, lid open
09/13/2001	NE corner	385	1 60	1 57	219	no afterburner, lid open
09/13/2001	NW corner	382	3 57	3 80	na	no afterburner, lid open
09/13/2001	SE corner	148	12 9	13 1	na	no afterburner, lid open
09/13/2001	SW corner	391	2 75	2 97	439	no afterburner, lid open

Table 15 Summary of the Area Air Samples Collected Around the Kettle Tampa Bay Technical High School and West Park Village at West Chase			
Exposure Analyte	Mean Concentration		% Difference afterburner on/lid closed vs no afterburner/ lid open
	afterburner on/ lid closed	no afterburner/ lid open	
NTP TP (mg/m³)	0 12	4 30	97 2
NTP BSF (mg/m³)	0 10	4 50	97 8
NTP Total PAC (µg/m³)	11 1	428	97 5

Table 16A Roof-Level Worker NTP Exposure Concentrations Tampa Bay Technical High School						
Sample Date	Worker ID Number	Sample Time (min)	NTP TP Conc (mg/m^3)	NTP BSF Conc (mg/m^3)	NTP Total PAC Conc (μg/m^3)	Kettle Conditions
09/11/200	MP-02	434	0 68	0 56	na	afterburner on/lid closed
09/12/200	MP-02	317	0 38	0 30	64 3	afterburner on/lid closed
09/13/200	MP-02	208	<0 07	<0 08	80 1	afterburner on/lid closed
09/11/200	MP-03	440	0 37	0 36	73 6	afterburner on/lid closed
09/12/200	MP-03	316	0 87	0 80	132	afterburner on/lid closed
09/13/200	MP-03	206	0 35	0 37	57 1	afterburner on/lid closed

Table 16B Roof-Level Worker NTP Exposure Concentrations West Park Village at West Chase						
Sample Date	Worker ID Number	Sample Time (min)	NTP TP Conc (mg/m^3)	NTP BSF Conc (mg/m^3)	NTP Total PAC Conc (μg/m^3)	Kettle Conditions
09/11/200	MP-05	414	0 68	0 75	91 2	no afterburner/lid open
09/12/200	MP-05	288	<0 07	0 06	24 7	no afterburner/lid open
09/13/200	MP-05	369	0 41	0 36	47 8	no afterburner/lid open
09/11/200	MP-06	407	<0 04	<0 06	na	no afterburner/lid open
09/12/200	MP-06	317	0 22	0 37	27 7	no afterburner/lid open
09/13/200	MP-06	377	0 53	0 49	62 3	no afterburner/lid open

Table 17 Summary of the Roof level Workers' NTP Exposure Results Tampa Bay Technical High School and West Park Village at West Chase			
Exposure Analyte	Mean Concentration		% Difference afterburner on/lid closed vs no afterburner/ lid open
	afterburner on/ lid closed	no afterburner/ lid open	
NTP TP (mg/m^3)	0 44	0 31	-43 1
NTP BSF (mg/m^3)	0 40	0 34	-17 3
NTP Total PAC (μg/m^3)	81 5	54 8	-48 8

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 an afterburner system with a safety loading door A summary of these analyses is shown in Table 18 Comparisons were made between air sample results for NTP TP, BSF, and total PAC while the afterburners were off and the kettle lid was open and when the afterburner was on and the kettle lid was closed Comparisons were made for the following groups the kettle operator, the four area air samples collected around the kettle, and the roof-level workers Included in Table 18 are percent reductions in exposure to the mean NTP TP, BSF, and total PAC, p-values, t-values, and critical t-values at 95% confidence

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 for TP and BSF and all the area air samples collected around the kettle were statistically significant The PAC reductions for the kettle operator as well as all the reductions measured for the roof level workers were not statistically significant at 95% confidence Adjusting the exposure results to NTP did not alter the significance

Table 18 Summary of Statistical Analyses of the NTP Exposure Results					
Comparison Group/Analyte	Afterburner/ Kettle Lid Condition	Percent Difference in Exposure	p-value	t-value	Critical t at 95% confidence
Kettle Operator/NTP TP	none/open vs on/closed	**94.12**	0 009	**3.83**	2 13
Kettle Operator/NTP BSF	none/open vs on/closed	**97 50**	0 012	**3 51**	2 13
Kettle Operator/NTP Total PAC	none/open vs on/closed	91 62	0 009	1 76	2 35
Area Samples Around Kettle/NTP TP	none/open vs on/closed	**97 35**	0 00005	**4 83**	1 72
Area Samples Around Kettle/NTP BSF	none/open vs on/closed	**97 93**	0 00008	**4 64**	1 72
Area Samples Around Kettle/NTP Total PAC	none/open vs on/closed	**97 77**	0 00011	**4 54**	1 73
Roof-Level Workers/NTP TP	none/open vs on/closed	-33 40	0 27	-0 64	1 81
Roof-Level Workers/NTP BSF	none/open vs on/closed	-8 95	0 42	-0 20	1 81
Roof-Level Workers/NTP Total PAC	none/open vs on/closed	-37 29	0 13	-1 23	1 83

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 at the West Park Village construction site where there were no afterburners and the kettle lid was open The kettle operator's exposures at the Tampa Bay Technical High School to TP, BSF, and total PAC were all less than those measured for the kettle operator at the West Park Village site Percent differences in exposures of 93 7%, 97 3%, and 91 1% for TP, BSF, and total PAC, respectively, were measured between the kettle operator at the Tampa Bay Technical High School and the kettle operator at the West Park Village construction site All of the percent differences measured were statistically significant at 95% confidence Similarly, the mean exposure concentrations for the four area air samples collected around the kettle had percent differences of 97 2%, 97 8%, and 99 4% in TP, BSF, and total PAC exposures when comparing exposures measured at the Tampa Bay Technical High School to the exposures measured at the West Park Village construction site These percent differences were all statistically significant at 95% confidence Unlike the kettle operators and the area air samples collected around the kettles, the TP, BSF, and total PAC exposures were somewhat higher in the roof level workers at the Tampa Bay Technical High School than they were for the roof level workers at West Park Village Mean TP, BSF and total PAC exposure for the roof level workers at Tampa Bay Technical High School were 0 45 mg/m^3, 0 41 mg/m^3, and 82 6 $\mu g/m^3$, respectively Mean TP, BSF and total PAC exposure for the roof level workers at West Park Village were 0 34 mg/m^3, 0 37 mg/m^3, and 55 3 $\mu g/m^3$, respectively

When the exposure concentrations were adjusted to NTP the percent difference in exposures for the Tampa Bay Technical High School site when compared to the West Park Village construction site were all similar All percent differences that were statistically significant in the measured exposure concentrations remained statistically significant when the concentrations were adjusted to NTP

CONCLUSIONS

Using an afterburner system with a safety loading door to add asphalt to the kettle clearly reduces exposure to asphalt fumes to the kettle operator The kettle operator's mean TP, BSF, and total PAC exposures at the Tampa Bay Technical High School were all statically significantly lower than the kettle operator's mean exposures at the West Park Village construction site Comparison of the area air samples collected at the two sites supports the results seen for the kettle operators The exposure reductions were not seen when comparing the roof level workers The mean TP, BSF, and total PAC exposure levels at both sites were similar and did not appear to be affected by the presence of the afterburner system used at the Tampa Bay Technical High School There are variables which could have affected the results that were not taken into account Variables such as the differences between the two kettles and the amount of asphalt used at the two sites may have affected the outcomes Because these factors were not taken into account, drawing strong conclusions from these surveys is not possible although the percent differences between the kettle operators' exposures were statistically significant

REFERENCES

1 CPWR [1993] Final report An investigation of health hazards on a new construction project Washington, DC The Center To Protect Workers' Rights

2 Partanen T, Boffetta P [1994] Cancer risk in asphalt workers and roofers review and meta-analysis of epidemiological studies Am J Ind Med 26 721-747

3 Mommsen S, Aagard J, Sell A [1983] An epidemiological study of bladder cancer in predominantly rural districts Scand J Urol Nephrol 17(3) 307-312

4 Risch HA, Burch JD, Miller AB, Hill GB, Steele R, Howe GR [1988] Occupational factors and the incidence of cancer of the bladder in Canada Br J Ind Med 45(6) 361-367

5 Bonassi, S, Merlo F, Pearce N, Puntoni R [1989] Bladder cancer and occupational exposure to polycyclic aromatic hydrocarbons Int J Cancer 44 648-651

6 Jensen OM, Knudsen JB, McLaughlin JK, Sorensen BL [1988] The Copenhagen case-control study of renal, pelvis, and uteran cancer role of smoking and occupational exposure Int J Cancer 41(4) 557-561

7 Hansen ES [1989] Cancer mortality in the asphalt industry a 10-year follow-up of an occupational cohort Br J Ind Med 46(8) 582-585

8 Austin H, Delzell E, Grufferman S, Levine R, Morrison AS, Stolley PD, Cole P [1987] Case control study of hepatocellular carcinoma, occupational and chemical exposures J Occup Med 29(8) 665-669

9 Siemiatycki J (editor) [1991] Risk factor for cancer in the workplace Boca Rotan, FL CRC Press

10 Menck HR, Henderson BE [1976] Occupational differences in rates of lung cancer J Occup Med 18 797-801

11 Engholm G, Englund A, Linder B [1991] Mortality and cancer incidence in Swedish road paving asphalt workers and roofers Health Environ 1 62-68

12 Hrubec Z, Blair AE, Rogot E, Vaught J [1992] Mortality risks by occupation among U S veterans of known smoking status (1954-1980) U S Department of Health and Human Services Public Health Service, National Institute of Health (NIH), NIH Publication No 92-3407

13 Pukkala E [1995] Cancer nsk by social class and occupation A survey of 109,000 cancer cases among Finns of working age New York Karger, p 53

14 Milham S [1997] Occupational mortality in Washington State 1950-1989 Order No 00913725 U S Department of Health and Human Services (DHHS), Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH), Division of Surveillance, Hazard Evaluations, and Field Studies, Cincinnati, OH DHHS (NIOSH) Publication No 96-133

15 Zahm SH, Brownson RC, Chang JC, Davis JR [1989] Study of lung cancer histologic types, occupational, and smoking in Missouri Am J Ind Med 15 565-578

16 Schoenberg JB, Sternhagen A, Mason TJ, Patterson J, Bill J, Altman R [1987] Occupational and lung cancer risk among New Jersey white males J Nat Can In

17 Butler MA, Burr G, Dankovic D, Lunsford RA, Miller A, Nguyen M, Olsen L, Sharpneck D, Snawder J, Stayner L, Sweeney MH, Teass A, Wess J, Zumwalde R [2000] Hazard Review Health Effects of Occupational Exposure to Asphalt U S Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No 2001-110

18 CDC [1990] Healthy People 2000 Objectives, 10 2 Reduce work related injuries Atlanta, GA U S Department of Health and Human Services (DHHS), Public Health Service, Centers for Disease Control and Prevention

19 NIOSH [1996] Control Technology and Personal Protective Equipment NIOSH National Occupational Research Agenda (NORA) Http //www cdc gov/niosh/nrppe html

20 OSHA [1995] OSHA Priority Planning Process Washington, D C

21 Herbert III RD, [1989] Roofing Design Criteria, Options, Selection Kingston, MA R S Means Company, Inc , pp 59-65

22 OSHA [1993] Occupational Safety and Health Administration Part 1926 Safety and Health Regulations for Construction, Subpart D Occupational Health and Environmental Controls 1926 55 Gases, Vapors, Fumes, Dusts, and Mists

23 53 Federal Register 21193 [1988] Occupational Safety and Health Administration Air contaminants, proposed rules Washington, DC U S Government Printing Office, Office of the Federal Register

24 54 Federal Register 2679 [1989] Occupational Safety and Health Administration Air contaminants, final rule Washington, DC U S Government Printing Office, Office of the Federal Register

25 57 Federal Register 26182 [1990] Occupational Safety and Health Administration Air contaminants, final rule Washington, DC U S Government Printing Office, Office of the Federal Register

26 OSHA [1990] Occupational Safety and Health Administration 29 Code of Federal Regulations Part 1990 Identification, Classification, and Regulation of Carcinogens

27 NIOSH [1998] NIOSH Testimony on the Occupational Safety and Health Administration's proposed rule on air contaminants, August 1, 1988 NITS No PB-91-115-337

28 Niemeier RW, Thayer PS, Menzies KT, Von Thuna P, Moss CE, Burg J [1988] A comparison of the skin carcinogenicity of condensed roofing asphalt and coal tar pitch fumes In Cook m, Dennis AJ, eds Polynuclear aromatic hydrocarbons A decade of progress Tenth International Symposium on Polynuclear Aromatic Hydrocarbons Columbus, OH Battelle Press, pp 609-647

29 American Conference of Governmental Industrial Hygienists (ACGIH) 2001 2001 TLVs® and BEIs® Threshold limit values for chemical substances and physical agents, biological exposure indices Cincinnati, Ohio ACGIH

30 NIOSH [1977] Criteria for a recommended standard Occupational exposure to asphalt fumes Cincinnati, OH U S Department of Health, Education, and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No 78-106, NITS Publication No PB-277-333

31 Exxon [1997] Shift study of pulmonary function and symptoms in workers exposed to asphalt fumes Final report submitted to Asphalt Industry Oversight Committee East Millstone, NJ Exxon Biomedical Sciences, Inc , Report No 97TP31

32 Gamble JF, Nicolich MJ, Barone NJ, Vincent WJ [1999] Exposure-response of asphalt fumes with change in pulmonary function and symptoms Scand J Work Environ Health 25(3) 186-206

33 Sivak A, Menzies K, Beltis K, Worthington J, Ross A, Latta R [1989] Assessment of the co carcinogenic promoting activity of asphalt fumes Cincinnati, OH U S Department of Health and Human Services, Public Health Service, Centers for Disease Control and

Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No 200-83-2612, NITS Publication No PB-91-110-213

34 Sivak A, Niemeier R, Lynch D, Beltis K, Simon S, Salomon R, Latta R, Belinky B, Menzies K, Lunsford A, Cooper C, Ross A, Bruner R [1997] Skin carcinogenicity of condense asphalt roofing fumes and their fractions following dermal application to mice Cancer Lett 117 113-123

35 Kriech AJ, Kurek JT [1993] A comparison of field versus laboratory generated asphalt fumes A report submitted to the NIOSH Docket by the Heritage Research Group Indianapolis, IN, Unpublished

36 NIOSH [1984] Eller PM, ed NIOSH manual of analytical methods 3rd rev ed Cincinnati, OH U S Department of Health and Human Services, Public Health Services, Centers For Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No 84-100

37 Dean RB, Dixon WJ [1951] Analytical Chemistry 23 636