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Coal Tar Pitch Volatiles and Polycyclic Aromatic Hydrocarbons Exposures in Expansion Joint–Making Operations on a Construction Site: A Case Study

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This case study describes occupational exposures to coal tar pitch volatiles (CTPV) as benzene soluble fraction (BSF), polycyclic aromatic hydrocarbons (PAHs) and total particulates at a unique operation involving the use of coal tar in the making of expansion joints in construction of a multi-level airport parking garage. A task-based exposure assessment approach was used. A set of 32 samples was collected and analyzed for total particulate and CTPV-BSF. Twenty samples of this set were analyzed for PAHs. Current American Conference of Governmental Industrial Hygienists (ACGIH®) respective threshold limit value–time weighted average (TLV-TWA) for insoluble particulates not otherwise specified (PNOS) is 10 mg/m^3 as inhalable dust, which roughly corresponds to 4 mg/m^3 total particulate; for CTPV as BSF the TLV is 0.2 mg/m^3, and for specific PAHs such as benzo(a)-pyrene (B[a]P), ACGIH suggests keeping exposure as low as practicable. The recommended Swedish exposure limit for B(a)P is 2 μg/m^3. The highest exposure levels measured were 12.8 mg/m^3 for total particulate, 1.9 mg/m^3 for coal tar pitch volatiles as BSF, and 12.8 μg/m^3 for B(a)P. Several of the CTPV-BSF results were over the TLV of 0.2 mg/m^3. The data set is limited; therefore, caution should be used in its interpretation.

Keywords Coal Tar Pitch Volatile (CTPV), Benzene Soluble Fraction (BSF), Polycyclic Aromatic Hydrocarbons (PAHs), Benzo(a)pyrene (B[a]P), Total Particulates, Task-Based Assessment, Construction, Expansion Joint

Coal tar is the by-product formed during the destructive distillation of coal in a process known as carbonization, or coking. It is a viscous black or dark brown material consisting of high molecular weight hydrocarbons and benzene, toluene, phenol, styrene, cresol, naphthalene, and numerous polycyclic aromatic hydrocarbons (PAHs), which can become airborne when heated.[1,2] The International Agency for Research on Cancer (IARC) has classified the coal tar pitch volatiles as a Group 1 carcinogen.[3,4]

Most studies report acute effects, primarily on the skin and eyes. Coal tar, pitch creosote, coke oven emissions, and asphalt exposure can result in the formation of skin tumors and/or lung tumors in animals. A recent proportionate mortality study among roofers and waterproofers found workers to have a significant increased mortality for lung and bladder cancers.[5] This group is known to have exposure to asphalt and bitumen products.

Boffetta et al. concluded that heavy exposure to PAHs from coal tar products correlated to a substantial risk of lung, skin, and bladder cancers.[6] Due to the potential health effects attributed to coal tar usage, this material has largely been replaced in the Ontario construction industry with asphalt-based materials for road, roofing, and waterproofing work.

Asphalt, a dark brown to black cement-like material, which is primarily comprised of bitumens, contains very high molecular weight hydrocarbons called asphaltenes. Asphalt is soluble in oil, turpentine, petroleum, carbon disulphide, and insoluble in water, alcohol, and acid. It is a constituent of crude petroleum and also occurs as a natural deposit, which is the resulting residue from the evaporation and oxidation of liquid petroleum. The chemical composition of asphalt varies depending upon the refining process and the source of crude oil used. Asphalt has often been confused with coal tar because the two are similar in appearance. However, even limited chemical analysis shows the two substances to be quite different, especially in the proportion of PAHs and known carcinogenic chemical.[2] Coal tar–based material is known to result in a far greater exposure to PAHs than asphalt-based material. Recently, a unique process involving occupational exposure to coal tar pitch volatiles as benzene solubles fraction (CTPV-BSF) and PAHs was investigated as part of a larger study currently in progress examining the mortality, cancer incidence, and workplace exposure among Ontario construction workers.[7]

A new airport terminal under construction in Toronto, Ontario, included a large, 8-level parking garage (8500 parking spaces) consisting of 13 segments built on separate foundations. This was to permit flexibility in the structure due to effects from seismic disturbances, thermal expansion/contraction, wind, traffic, and so on. Various activities were investigated at this site including form-building and concrete-pouring, concrete finishing, terrazzo laying, interior electrical and pipe finishing, and expansion joint construction.

An expansion joint constructed of a polyurethane elastomeric concrete (PEC) material was used to help connect each of the building segments together. The joint, comprised of the PEC material, aluminum hardware rails, and metal cover plates is designed to respond to seismic disturbances and thermal expansion/contraction without affecting the structural integrity of the building. A proprietary PEC product, known in Canada as Polycrete and LokCrete in the United States, was used at this construction site. It consisted of dry ingredients (an aggregate binder of stone, sand, and white finishing powder) and wet ingredients (a mixture of an amine-based epoxy and a hardener containing coal tar derivatives). The PEC was applied using a hot trowel into extruded aluminum rails installed on roughed-in concrete joints. The PEC was used for three reasons: bonding strength, resistance to cracking, and workability. A crew of 12 to 14 laborers and a foreman are involved in various stages of the activity.

Unlike industrial environments, construction activities tend to be highly variable with each trade. The Task-Based Exposure Assessment Model was used as the basis for this evaluation, which uses tasks (or specialized skills) as the central method for data collection.[8] In performing our analysis of this operation, we observed and identified major tasks, categorizing them along the lines of major work groups, reviewed material safety data sheets for potential exposures, and carried out task-based monitoring for CTPV-BSF, PAHs, and particulates. To the best of our knowledge, occupational exposures to hazardous agents such as CTPV-BSF and PAHs in the expansion joint–making operation have not been reported in the published literature. The objective of this article is to present the results of the task-based exposure assessment on this unique operation.

MATERIALS AND METHODS

Process Description

A setup team of three to four workers is responsible for preparing the roughed-in concrete for the pouring of PEC. This team prepares the joint by cleaning the concrete and installing base plates of extruded aluminum forms. A base-coat team of two to three workers lays down a thin coat of wet ingredients (no dry ingredients) as a primer. The primer coat is then covered with a thicker coat of PEC material (containing both wet and dry ingredients). Prior to the curing of this PEC material, this team will install the top-rails, creating a pocket in which the main coat will be worked in. The base-coat team performs mixing, troweling, and top-rail installation. A top-coat team installs the main coat of PEC. This team is comprised of 5 workers who mix, trowel, or help clean trowels. This crew will lay down the PEC continuously. In winter when a segment is finished, workers wheel propane-fired heaters into place to speed up the curing of the PEC.

Finishing teams of one or two other workers install waterproofing barriers on ceilings under the expansion joints and cover plates on top of the joints. The foreman oversees the operation, coordinates supply shipments, and participates in the application process if a team is shorthanded. A job-task breakdown of the operation is given in Table I. Primary exposure to the PEC occurs during mixing, troweling, and trowel cleaning. Usually the epoxy and hardener are heated to 35°C in order to maintain fluidity of the materials. At this temperature, there is no perceptible level of fumes or vapors emitted from this product. However, during mixing and troweling, the product is superheated in order to promote mixing and flow into the joint.

Three specific tasks that are sources of occupational exposures identified as mixing, troweling, and trowel cleaning are shown in Figure 1. During mixing, a measured quantity of 2 parts (approximately 2 liters) component A epoxy and 1 part component B hardener, also referred to as curing agent (containing coal tar), are dispensed from storage vessels into a small mixing pot. The two products are mixed using an electric drill with mixing extension. While the epoxy/hardener receives initial mix, a laborer places a mixing drum on an electric turntable into which 1 bag (approximately 16 kg) of aggregate (dry ingredients) composed of sand, white finishing powder, and 1-cm-diameter stone is added. While mixing the fresh aggregate, the mixer preheats the aggregate to approximately 35°C using a propane torch (warm to the touch). During this task, a plume of yellowish black smoke is emitted from the mixing drum due to epoxy/hardener material burning off from the a previous batch, which surrounds the mixer and immediate downwind area. This smoke can also be emitted when the mixer cleans out this drum and various mixing pots with a hot trowel.

Once heated properly, epoxy/hardener material is added to the aggregate and mixed together. The mix is then delivered to the trowelers. Trowel cleaning also exposes the helper to a plume of yellowish-black smoke. During the troweling operation, the helper cleans and heats the trowels by arranging them horizontally in a slotted 10-cm-diameter metal tube, heated with the same type of torch used in the mixing process. The helper takes the hot trowels and passes them to the trowelers, who require a fresh tool about every 30 to 50 seconds. The hot trowel makes the freshly mixed PEC material more viscous and facilitates penetration into the pockets under the aluminum rails. Smoke from the trowel is generated when it contacts the compound, either when it's scooped out of the drum or when the material is worked into the joint. Workers involved in setup, cleanup, or other operations in the area including other trades within the vicinity, are also exposed to the fumes, depending on wind direction and whether the work area is enclosed.

TABLE I
Task breakdown for expansion joint construction

Work Team	Task	Description	Equipment
Setup crew	Rail installation	Install aluminum extruded rails, springs, and shims	Impact drill, hand tools, Hilti epoxy caulk, silicone sealant
	Abrasive blasting	Roughen aluminum rails	Diesel compressor (Chicago Pneumatic/John Deere), ABEC sandblaster, B&M Black Shot #20
	Form preparation	Cut foam or wood shims, measure/cut rails, spray release agent on forms, and mask joints	Foam insulation, circular saw, wood, Dexter Frekote release agent
	Concrete preparation	Prepare concrete	Electric grinder, diesel compressor (Chicago Pneumatic/John Deere)
		Clean joint with compressed air	
Base-coat crew	Mixing	Mix primer coat of epoxy and hardener	Drill-based mixer, epoxy vessels
		Mix mid-coat of epoxy, hardener, and aggregate	
	Helping	Heat trowels to smoking temperature	Large-volume propane torch, trowel
		Clean trowels	
	Troweling	Work primer and mid-coats into joint	Trowel
	Top rail installation	Install top rail over base rail	Drill, hand tools
	Heater installation (winter)	Place propane heaters overtop finished base coat	Propane heater
Top-coat crew	Mixing	Mix aggregate, epoxy, and hardener	Hand drill mixer trowel, drum mixer, large volume
		Deliver mix to trowelers	Propane torch
	Helping	Clean/preheat trowels	Large-volume propane torch, trowel
	Troweling	Work top coat into joint and trowel in smooth	Trowel
	Heater installation (winter)	Place propane heater over finished joint to set epoxy	Propane heater
Finishing crew	Install top plates	Install protective top plate over joint	Drill, hand tools
	Moisture barrier installation	Insulate joint, install polysheet barrier	Drill, hand tools, poly barrier
Foreman	Oversees operation	Administrative matters	Various
		Performs any task where needed	
Miscellaneous	Delivering supplies	Move materials in and out of area	Forklift (propane)
	Cleanup	Various	Various

FIGURE 1
Expansion Joint Making Operation (a) Mixing LokCrete (b) Mixing expansion joint compound (c) Troweling (d) Trowel cleaning.

Sampling and Analysis

CTPV-BSF samples were collected on pre-weighed 37-mm, 2.0-μm Teflon Zefluor filters (Gelman Laboratories, Pall Corporation, Ann Arbor, MI, USA) in-line with Orbo 43 XAD-2 Tubes (Supelco, Bellefonte, PA, USA) covered in aluminum foil to prevent degradation due to light. The filters were connected to air sampling pumps set at 2.0 $\pm$ 5% liters per minute using Tygon tubing. Short-term task-based samples were collected. When possible, personal breathing zone samples were collected. Due to awkward worker positioning, some laborers declined to wear the sampling train. In that event, area sampling was carried out by placing the collection devices within 1 to 1.5 meters of the activity with the inlet at the level of the worker's head. To obtain sufficient filter loading for coal tar pitch volatiles, some of the pumps were set at approximately 3.5 liters per minute to collect area samples using only a Teflon filter cassette. Full-shift environmental monitoring was carried out utilizing the complete sampling train (pump, filter, and tube) at various areas around the work area to observe effects of wind and assess the impact on workers in other areas.

The Teflon filters were first analyzed for total particulate on a Cahn C-44 microbalance using NIOSH Method 500[9] with modifications. CTPVs collected on these filters were analyzed as benzene solubles by extraction/gravimetric analysis using NIOSH Method 5042[10] with modifications. PAHs collected on the filters and XAD-2 tubes were analyzed by HPLC, UV/VIS detection using NIOSH Method 5506[11] with modifications. Quality control procedures were utilized both in field and laboratory. In the field, quality controls consisted of collection of blank samples and also pre- and post-calibration of sampling pumps. Stringent laboratory quality controls were in place, including analysis of spikes, repeat analysis, and analysis of a different source material other than material used for standard curve.

RESULTS

The results of personal and area samples taken are summarized in Tables II and III. Two samples listed in Table III are background samples of other trades indirectly exposed in an

TABLE II
Summary of samples by analyte

Analyte	N (below DL)[A]	Concentration (μg/m^3) AM	GM	GSD	Min-Max
Total dust particulate[B]	32(0)	2.00[C]	1.12[C]	2.90	0.17–12.80[C]
CTPV-BSF[B]	32(17)	0.39[C]	0.22[C]	3.07	<0.38–1.93[C]
PAHs[B]					
Naphthalene	20(1)	130.09	45.89	5.89	<0.7–519
Acenaphthylene	20(20)	—	—	—	<0.7
Acenaphthene	20(14)	2.29	1.49	2.72	<0.35–8
Fluorene	20(3)	8.11	2.65	5.54	<0.08–41.6
Phenanthrene	20(4)	9.92	2.32	7.25	<0.04–68.9
Anthracene	20(4)	1.79	0.64	4.63	<0.04–8.76
Fluoranthene	20(4)	7.39	1.26	7.10	<0.08–60.5
Pyrene	20(4)	4.67	0.89	6.22	<0.04–37.8
Benzo(a)anthracene	20(4)	3.77	1.09	5.81	<0.04–21.2
Chrysene	20(4)	3.28	0.97	5.63	<0.04–19.8
Benzo(b)fluoranthene	20(5)	2.81	0.94	4.96	<0.08–17.9
Benzo(k)fluoranthene	20(6)	1.17	0.41	4.94	<0.04–7.1
Benzo(a)pyrene	20(4)	2.11	0.70	4.99	<0.04–12.8
Dibenzo(a,h)anthracene	20(18)	—	—	—	<0.08–1.5
Benzo(g,h,i)perylene	20(12)	0.96	0.38	3.91	<0.08–6.7
Indeno(1,2,3-cd)pyrene	20(7)	1.05	0.33	5.04	<0.04–8.1

[A]For results below the limit of detection, a value of one-half the detection limit has been used to compute estimated concentration.
[B]Sample volume range used was 31–706 liters.
[C]Values are measured in mg/m^3.
[D]N = Number of Samples; AM = Arithmetic Mean; GM = Geometric Mean; GSD–Geometric Standard Deviation.

adjacent area. One of these was taken in an area where terrazzo layers were working and the other on a scissor lift 15 meters from the work area which had been used periodically on one of the days by a pipe fitter. Table III summarizes the total particulate, CTPV-BSF, and B(a)P exposures for various tasks of the expansion joint workers. A comparison of summer and winter samples of CTPV samples is shown in Figure 2. The frequency distribution of CTPV-BSF and B(a)P, which is shown in Figure 3, exclude two results of other trades indirectly exposed (pipefitter and terrazzo layer workers). For statistical analyses, half the value of the detection limit has been used for samples below the limit of detection.

DISCUSSION AND CONCLUSIONS

The personal sample for the helper who cleans the trowels showed the highest CTPV-BSF concentration of 1.93 mg/m^3 and a B(a)P concentration of 12.8 μg/m^3. As expected, the lowest results from the task-based samples were during setup and finishing activities. The higher concentrations were observed during mixing and troweling. Sampling was mainly conducted during winter (−10°C to 0°C) under sometimes windy conditions, affecting the personal sampling results where wind was a factor. Some samples were also collected during summer in June and July on hot days (25°C to 30°C) to determine whether outdoor temperature was a contributing factor. The median CTPV results of summer samples ($n = 8$) did not differ appreciably from those collected during winter ($n = 23$), as can be seen in Figure 2 of the statistical comparison using Minitab version 12.

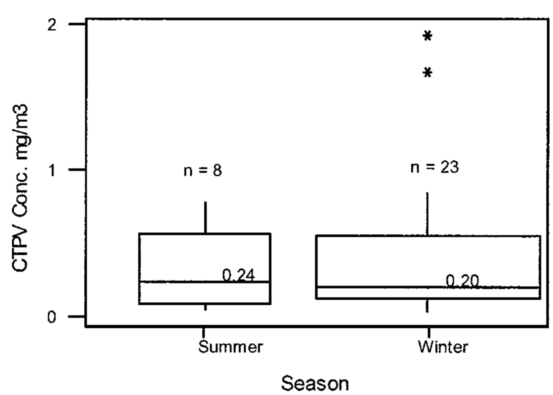

FIGURE 2
Distribution of CTPV samples: Summer vs. winter.

TABLE III
Summary of total particulate, CTPV-BSF, and B(a)P concentrations by task

Trade/Task	N TP/CTPV (PAH)	Type	Sampling duration (minutes)	Total dust particulate concentration (mg/m^3)			CTPV-BSF concentration (mg/m^3)			Benzo(a)pyrene concentration ($\mu g/m^3$)		
				Min	Max	Median	Min	Max	Median	Min	Max	Median
Expansion Joint Workers												
Mixing	3(2)	P	55–173	2.48	6.52	3.38	BDL	0.84	0.16	1.1	2.70	—
	4(2)	A	106–299	0.38	1.19	0.96	BDL	0.20	0.12	0.13	0.60	—
Troweling	4(3)	P	16–181	0.76	12.8	1.20	BDL	0.78	BDL	1.1	8	1.1
	5(3)	A	43–280	0.38	2.54	0.77	BDL	0.55	BDL	0.07	1.9	0.49
Troweling/Mixing/Setup	2(1)	P	76–111	0.83	4.95	—	0.14	1.67	—	6.43	—	—
Heating/Cleaning Trowels	4(2)	P	50–192	1.33	3.14	1.42	0.56	1.93	0.66	3.9	12.8	—
Setup	2(1)	P	49	0.24	1.49	—	BDL	BDL	—	BDL	BDL	—
	5(3)	A	27–353	0.37	5.61	0.58	BDL	0.41	BDL	BDL	0.49	0.15
Finishing	1(1)	A	271	0.17	—	—	BDL	—	—	BDL	—	—
Other Trades (Indirectly Exposed)												
(pipe fitter/terrazzo layer workers)	2(2)	A	60–344	0.5	0.7	—	BDL	0.10	—	BDL	0.48	—

P = Personal; A = Area; BDL = Below Detection Limit; N = Number of samples.
Note: Same N for TP (total particulate) and CTPV (coal tar pitch volatiles) but PAH (polycyclic aromatic hydrocarbons) has specific N. If 1 sample, then value reported as min value; if 2 samples, then min-max values reported; and if 3 or more samples, min-max and median value reported.

The current ACGIH's respective TLV-TWA for insoluble particulates not otherwise specified (PNOS) is 10 mg/m^3 as inhalable particulate and 0.2 mg/m^3as benzene soluble aerosol for CTPV. The TLV of 10 mg/m^3 as inhalable particulate would roughly convert to 4 mg/m^3 total particulate (37-mm-diameter button off cassette sampler).(12) As can be seen from Tables II and III and Figure 3, some of the measured values are higher than these values. The recommended ACGIH TLV for specific PAHs such as B(a)P, chrysene, and others is to keep exposure as low as practicable. B(a)P is used as an important marker for carcinogenic PAHs. Currently, there is an assigned exposure limit of 2 $\mu g/m^3$ for B(a)P in Sweden(13)and in Germany.(14) Several of the results obtained exceed this value.

Our measurements for total particulate, CTPV-BSF, and PAHs were not for 8 hours, thus all of the data cannot be directly compared to TLV-TWAs. The data, however, do point out potential exposure to these carcinogenic substances in this operation. The highest personal sample CTPV-BSF concentration of 0.78 mg/m^3 for troweling, shown in Table III, was taken over 181 minutes. Assuming zero exposure for the remaining unsampled period, the calculated 8 hours TWA of 0.28 mg/m^3 would be in excess of the TLV-TWA of 0.20 mg/m^3. Similarly, the highest personal sample CTPV-BSF concentration of 1.67 mg/m^3 for troweling/mixing/setup task taken over 111 minutes would compute to an 8-hour TWA concentration of 0.38 mg/m^3. The highest personal sample CTPV-BSF concentration of 1.93 mg/m^3 for heating/cleaning of trowels task, collected over 61 minutes, would compute to an 8-hr TWA concentration of 0.24 mg/m^3. The high personal exposure B(a)P concentrations in $\mu g/m^3$ of 2.7, 8.0, 3.9, 6.43, and 12.8 were associated with sample durations of 57, 16, 111, 56, and 61 minutes, respectively. The results of the samples for heating and trowel cleaning of 12.8 $\mu g/m^3$ taken over 1 hr would likely exceed the Swedish limit of 2 $\mu g/m^3$, if one assumes minimal exposure during the unsampled period.

The background samples represent exposure to other trades that were indirectly exposed. The samples collected had concentrations of particulates and CTPV-BSF much lower than expansion joint workers, thus trades indirectly exposed should not be exposed to any significant hazard from the expansion joint making operation. The concentrations of airborne particulates and CTPV-BSF (identified as area samples) were generally lower than personal samples (see Table III). It is recognized that the reported exposure concentrations represent exposure situations for workers without respiratory protection. Actual exposure for those using respirators would be lower. Dermal exposure, which is a very important route of exposure, is not accounted for with the airborne concentration measurements.

Coal tar, more commonly known as pitch in the roofing and road building trades, has largely been replaced by asphalt. Most workers who have worked with pitch in the past, noted that this

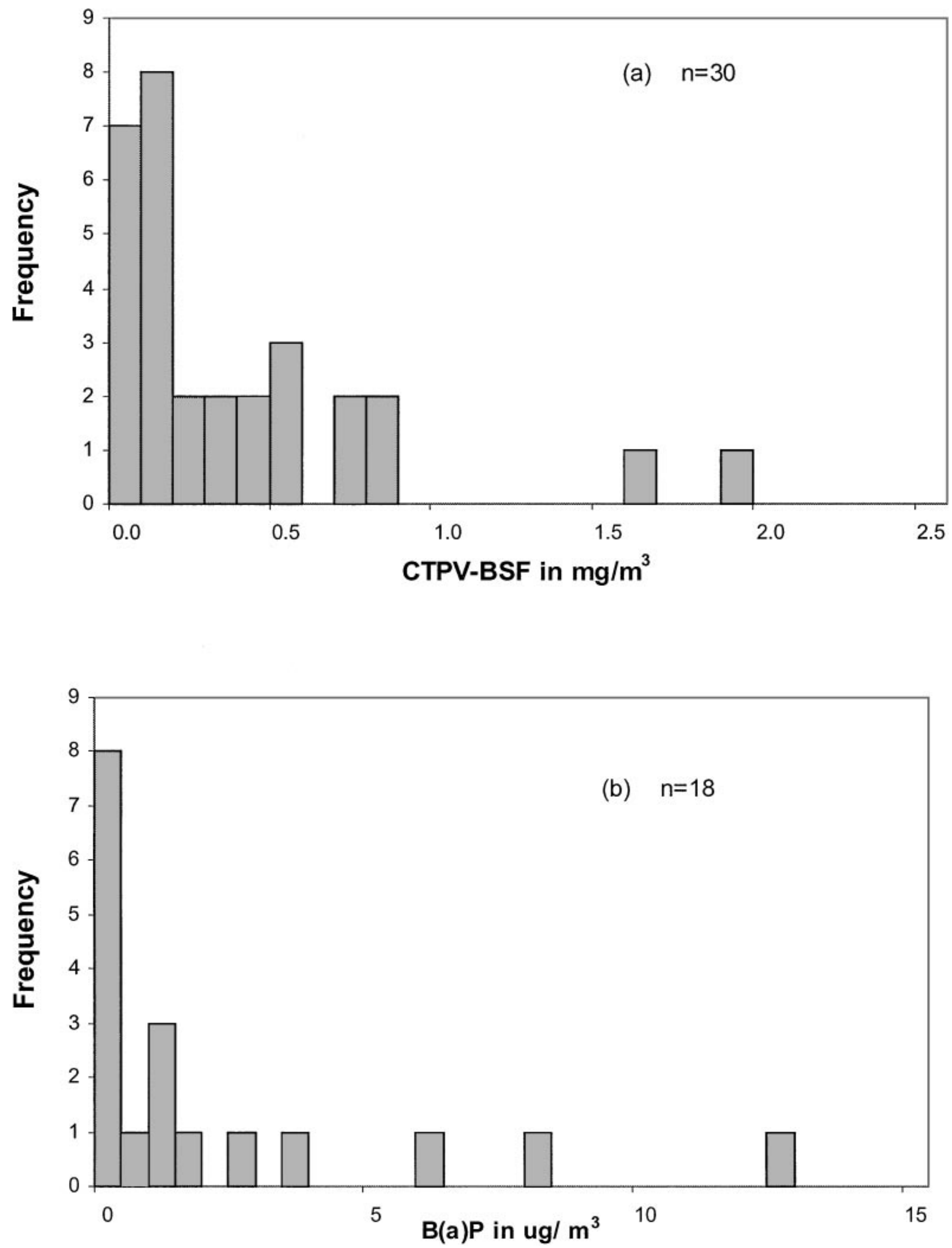

FIGURE 3
Frequency distribution of (a) CTPV-BSF and (b) benzo(a)pyrene concentrations.

material causes irritation that they perceived as being far more serious than the effects from asphalt. During this study we also had the opportunity to evaluate CTPV-BSF and PAHs exposures on a flat roofing job utilizing hot asphalt. CTPV-BSF concentrations of the kettle man and mop man, who were involved on this flat roofing job, yielded values far greater than those observed during the expansion joint operation. However, the PAH concentrations were in most cases non-detectable, or, if present, in concentrations far lower than those at the expansion joint operation described in the article.

During the 40–50 hour workweek, depending on overtime, workers spend on average 30 hours exposed. Workers wore either 3M 8210 N95 nosepiece dust masks, which were used by the setup crew, or Willson half-face masks with T08P100 particulate and organic vapor cartridges. Workers involved in setup wore respiratory protection intermittently, and respirator performance is likely compromised by the fact that many workers exhibited signs of several days of facial hair growth. They were also observed removing their masks to smoke cigarettes intermittently during the various activities, which might have an effect on PAH concentrations.

Dermal exposure is a major route of exposure and a health hazard in this particular operation so the importance of skin protection cannot be over emphasized. Dermal exposure is minimized during winter by the use of long-sleeved clothing and work gloves, but during summer, workers are at greater risk of dermal hazards from PEC material since short-sleeved shirts are worn. The only engineering control used at this particular work site was a large 50-cm axial floor fan to draw the smoke away from the faces of the trowelers. We recognize that our task-based data set is limited; thus, caution should be used in its interpretation.

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