www.cpwr.com • www.elcosh.org

CPWR

THE CENTER FOR CONSTRUCTION
RESEARCH AND TRAINING

**Topics in Construction Safety and Health**

# Asphalt in Construction:

## An Interdisciplinary Annotated Bibliography

CPWR - The Center for Construction Research and Training

2023

8484 Georgia Avenue
Suite 1000
Silver Spring, MD 20910

PHONE: 301.578.8500
FAX: 301.578.8572

©2023, CPWR-The Center for Construction Research and Training. All rights reserved. CPWR is the research and training arm of NABTU. Production of this document was supported by cooperative agreement OH 009762 from the National Institute for Occupational Safety and Health (NIOSH). The contents are solely the responsibility of the authors and do not necessarily represent the official views of NIOSH.

# Asphalt: An Interdisciplinary Annotated Bibliography

Anderson, S. E., et al. (2008). "The humoral immune response of mice exposed to simulated road paving-like asphalt fumes." J Immunotoxicol 5(3): 307-313.

Asphalt is a complex mixture of organic molecules, including polycyclic aromatic hydrocarbons (PAH), which have been reported to cause serious adverse health effects in humans. Workers in manufacturing and construction trades exposed to asphalt are potentially at risk for being exposed to asphalt fumes and PAHs. Epidemiological investigations have collected mounting evidence that chemicals found in asphalt fumes present carcinogenic and possibly immunotoxic hazards. Studies evaluating the immunotoxic effects of asphalt fume are limited due to the large number of variables associated with asphalt fume exposures. This work investigates the immuno-toxic effects of road paving-like asphalt fume by analyzing the in vivo IgM response to a T-dependent antigen after exposure to whole, vapor, and particulate phase road paving-like asphalt fumes and asphalt fume condensate. Systemic exposures via intraperitoneal injection of asphalt fume condensate (at 0.625 mg/kg) and the particulate phase (at 5 mg/kg) resulted in significant reductions in the specific spleen IgM response to SRBC. Pharyngeal aspiration of the asphalt fume condensate (at 5 mg/kg) also resulted in significant suppression of the IgM response to SRBC. A significant reduction in the specific spleen IgM activity was observed after inhalation exposure to whole asphalt fumes (35 mg/m(3)) and the vapor components (11 mg/m(3)). Dermal exposures to the asphalt fume condensate resulted in significant reductions in the total (at 50 mg/kg) and specific (at 250 mg/kg) spleen IgM response to SRBC. These results demonstrate that exposure to road paving-like asphalt fumes is immunosuppressive through systemic, respiratory, and dermal routes of exposure in a murine model and raise concerns regarding the potential for adverse immunological effects.

Asadi, S., et al. (2014). "Characterization of nano particles released during asphalt and concrete laboratory activities." International Journal of Pavement Research and Technology 7(3): 211-217.

Although nanomaterials possess new properties and their industrial application generates promising opportunities in construction, they also present new risks and uncertainties. To quantify the level of risks associated with engineered nanomaterials, research needs to first quantify the level of nanoparticles exposure encountered in different construction activities. Therefore, the objective of this study is to evaluate the potential inhalation exposure risk associated with Hot-Mix Asphalt (HMA) and Portland Cement Concrete (PCC) preparation activities in the laboratory. To achieve this objective, the number concentration, size distribution, surface area, and mass concentrationwere measured for different activities including dry mixing, wet mixing, pouring, and compaction in an asphalt and concrete laboratory using a Scanning Mobility Particle Sizer (SMPS). Results showed that more than 70% of the particles in the concrete preparation activities were ultrafine particles. In addition, workers in the concrete laboratory were exposed to relatively higher ultrafine particles concentrations than workers in the asphalt laboratory. The majority of the total particle number (49%) released during concrete laboratory activities was in the lowest size category, between 10-30 nm in diameter.Based on the results of this study, further research is needed to understand the negative effects of nanoparticles on the health of workers. © Chinese Society of Pavement Engineering.

Cavallari, J. M., et al. (2012). "Predictors of airborne exposures to polycyclic aromatic compounds and total organic matter among hot-mix asphalt paving workers and influence of work conditions and practices." Ann Occup Hyg 56(2): 138-147.

OBJECTIVES: We evaluated personal airborne exposures to polycyclic aromatic compounds (PACs) and total organic matter (TOM) among hot-mix asphalt (HMA) paving workers. The primary objectives of this study were to identify predictors of airborne PAC exposures, identify PAC exposure sources, and characterize how work practices may affect personal airborne exposure to PACs. METHODS: Four workers were recruited from each of three asphalt paving crews (12 workers) and were monitored for three consecutive days over 4 weeks for a total of 12 sampling days per worker (144 worker-days). Three sampling weeks were conducted while maintaining standard working conditions with regard to airborne exposures. The fourth week included the substitution of biodiesel for diesel oil used to clean tools and equipment. Linear mixed-effects models were used to evaluate predictors of airborne exposures including weather parameters (air temperature, wind speed, and relative humidity), worksite conditions (HMA application temperature, work rate, asphalt grade, and biodiesel use), and personal factors (minutes sampled, minutes of downtime, and smoking status). RESULTS: Concentrations of the 33 individual PACs measured in personal air samples were generally below detection limits under all conditions with the exception of fluorene [geometric mean (GM) = 65 ng m(-3)], naphthalene (GM = 833 ng m(-3)), phenanthrene (GM = 385 ng m(-3)), and pyrene (GM = 57 ng m(-3)). The summary measures of TOM (GM = 864 mug m(-3)) and four- to six-ring PAC (GM = 0.13 mug m(-3)) were detected in the majority of air samples. Although task was not a predictor of airborne exposures, job site characteristics such as HMA application temperature were found to significantly (P </= 0.001) affect summary and individual PAC exposures. Based on the results of multivariate linear mixed-effects models, substituting biodiesel for diesel oil as a cleaning agent was associated with significant (P </= 0.01) reductions in TOM, four- to six-ring PACs, and naphthalene and pyrene concentrations that ranged from 31 to 56%. Using multivariate linear mixed-effects models under standard conditions, reducing the application temperature of HMA from 149 degrees C (300 degrees F) to 127 degrees C (260 degrees F) could be expected to reduce airborne exposures by 42-82%, varying by analyte. CONCLUSIONS: Promising strategies for reducing airborne exposures to PACs among HMA paving workers include substituting biodiesel for diesel oil as a cleaning agent and decreasing the HMA application temperature.

Cavallari, J. M., et al. (2012). "Predictors of dermal exposures to polycyclic aromatic compounds among hot-mix asphalt paving workers." Ann Occup Hyg 56(2): 125-137.

OBJECTIVES: The primary objective of this study was to identify the source and work practices that affect dermal exposure to polycyclic aromatic compounds (PACs) among hot-mix asphalt (HMA) paving workers. METHODS: Four workers were recruited from each of three asphalt paving crews (12 workers) and were monitored for three consecutive days over 4 weeks for a total of 12 sampling days per worker (144 worker days). Two sampling weeks were conducted under standard conditions for dermal exposures. The third week included the substitution of biodiesel for diesel oil used to clean tools and equipment and the fourth week included dermal protection through the use of gloves, hat and neck cloth, clean pants, and long-sleeved shirts. Dermal exposure to PACs was quantified using two methods: a passive organic dermal (POD) sampler specifically developed for this study and a sunflower oil hand wash technique. Linear mixed-effects models were used to evaluate predictors of PAC exposures. RESULTS: Dermal exposures measured under all conditions via POD and hand wash were low

with most samples for each analyte being below the limit of the detection with the exception of phenanthrene and pyrene. The geometric mean (GM) concentrations of phenanthrene were 0.69 ng cm(-2) on the polypropylene layer of the POD sampler and 1.37 ng cm(-2) in the hand wash sample. The GM concentrations of pyrene were 0.30 ng cm(-2) on the polypropylene layer of the POD sampler and 0.29 ng cm(-2) in the hand wash sample. Both the biodiesel substitution and dermal protection scenarios were effective in reducing dermal exposures. Based on the results of multivariate linear mixed-effects models, increasing frequency of glove use was associated with significant ($P < 0.0001$) reductions for hand wash and POD phenanthrene and pyrene concentrations; percent reductions ranged from 40 to 90%. Similar reductions in hand wash concentrations of phenanthrene ($P = 0.01$) and pyrene ($P = 0.003$) were observed when biodiesel was substituted for diesel oil as a cleaning agent, although reductions were not significant for the POD sampler data. Although task was not a predictor of dermal exposure, job site characteristics such as HMA application temperature, asphalt grade, and asphalt application rate (tons per hour) were found to significantly affect exposure. Predictive models suggest that the combined effect of substituting biodiesel for diesel oil as a cleaning agent, frequent glove use, and reducing the HMA application temperature from 149 degrees C (300 degrees F) to 127 degrees C (260 degrees F) may reduce dermal exposures by 76-86%, varying by analyte and assessment method. CONCLUSIONS: Promising strategies for reducing dermal exposure to PACs among asphalt paving workers include requiring the use of dermal coverage (e.g. wearing gloves and/or long sleeves), substituting biodiesel for diesel oil as a cleaning agent, and decreasing the HMA application temperature.

Cavallari, J. M., et al. (2012). "Temperature-dependent emission concentrations of polycyclic aromatic hydrocarbons in paving and built-up roofing asphalts." Ann Occup Hyg 56(2): 148-160.

OBJECTIVES: To characterize temperature-dependent emissions from paving and built-up roofing asphalt (BURA) and to quantify differences in temperature-related concentrations and composition. METHODS: Using headspace gas chromatography, 18 polycyclic aromatic hydrocarbon (PAH) emission concentrations were quantified over eight temperatures (120-315 degrees C) for paving asphalt ($n = 20$) and Types II, III, and IV BURA ($n = 5$) and were summarized by geometric means (GMs) and geometric standard deviations (GSDs) at each temperature. The relationships between temperature and concentration were evaluated for PAH analytes using mixed-effects regression models. Temperature was categorized into regimes: Regime 1 (120-150 degrees C) representing temperatures typical of paving asphalt application, Regime 2 (180-230 degrees C) representing temperatures typical of BURA application, and Regime 3 (260-315 degrees C) which were high temperatures outside typical application temperatures. An interaction term was used to evaluate differential effects of temperature on paving asphalt versus BURA. RESULTS: In the paving regime (120-150 degrees C), paving asphalt emission concentrations were highest for 2- and 3-ring PAHs [GM (GSD) at 150 degrees C of 4.51 (2.07), 3.77 (1.63), 2.26 (1.53), and 1.80 (1.66) mug m(-3) for 2-methyl naphthalene, naphthalene, phenanthrene, and acenaphthene, respectively], with all the 4- and 5- to 6-ring individual PAHs mean concentrations below the detection limit, with the exception of benz[a]anthracene. In the BURA regime (180-230 degrees C), BURA emission concentrations were highest for 2- and 3-ring PAHs [GM (GSD) at 205 degrees C of 121.3 (1.37), 99.5 (1.31), 69.5 (1.32), and 68.1 (1.37) mug m(-3) for acenaphthene, anthracene, 2-methyl naphthalene, and phenanthrene, respectively], with lower but detectable concentrations for 4- and 5- to 6-ring PAHs. For both paving asphalt and BURA, concentrations increased log linearly with

temperature. At a given temperature, the highest concentrations were observed for 2-ring PAHs with lower and decreasing concentrations observed with increased ring size. Temperature was a statistically significant ($P < 0.01$) predictor of concentration for each analyte. Furthermore, the categorical temperature regime variable explained a large percent of the variability in concentrations accounting for 74-92% of the total variability in PAH concentration. In both paving asphalt and BURA, the relationship between temperature and concentration was non-linear. There was a statistically significant difference between paving asphalt and BURA in the temperature-concentration relationship for the each analyte. Temperature alone did not account for differences in paving asphalt and BURA concentrations in 5- to 6-ring PAHs. CONCLUSIONS: Emission concentrations are driven by temperature for both paving asphalt and BURA samples under studied experimental conditions. There are differences in paving asphalt and BURA emission concentrations that are not explained by temperature alone; concentrations were higher and consisted of larger ring (4 and 5 to 6) PAHs for BURA as compared to paving asphalt at the respective application temperature ranges.

Chang, C., et al. (2015). "Moving research to practice through partnership: A case study in Asphalt Paving." Am J Ind Med 58(8): 824-837.

Background: Multi-stakeholder partnerships play a critical role in dissemination and implementation in health and safety. To better document and understand construction partnerships that have successfully scaled up effective interventions to protect workers, this case study focused on the collaborative processes of the Asphalt Paving Partnership. In the 1990s, this partnership developed, evaluated, disseminated, and achieved near universal, voluntary adoption of paver engineering controls to reduce exposure to asphalt fumes. Methods: We used in-depth interviews (n=15) and document review in the case study. Results: We describe contextual factors that both facilitated and challenged the formation of the collaboration, central themes and group processes, and research to practice (r2p) outcomes. Conclusions: The Asphalt Paving Partnership offers insight into how multi-stakeholder partnerships in construction can draw upon the strengths of diverse members to improve the dissemination and adoption of health and safety innovations and build a collaborative infrastructure to sustain momentum over time. Am. J. Ind. Med. 58:824-837, 2015. © 2015 Wiley Periodicals, Inc.

Clark, C. R., et al. (2011). "Asphalt fume dermal carcinogenicity potential: I. dermal carcinogenicity evaluation of asphalt (bitumen) fume condensates." Regul Toxicol Pharmacol 61(1): 9-16.

Asphalt (bitumen) fume condensates collected from the headspace above paving and Type III built up roofing asphalt (BURA) tanks were evaluated in two-year dermal carcinogenicity assays in male C3H/HeNCrl mice. A third sample was generated from the BURA using a NIOSH laboratory generation method. Similar to earlier NIOSH studies, the BURA fume condensates were applied dermally in mineral oil twice per week; the paving sample was applied 7 days/week for a total weekly dose of 50 mg/wk in both studies. A single benign papilloma was observed in a group of 80 mice exposed to paving fume condensate at the end of the two-year study and only mild skin irritation was observed. The lab generated BURA fume condensate resulted in statistically significant ($P<0.0001$) increases in squamous cell carcinomas (35 animals or 55% of animals at risk). The field-matched BURA condensate showed a weaker but significant ($P=0.0063$) increase (8 carcinomas or 13% of animals) and a longer average latency (90 weeks vs. 76 for the lab fume). Significant irritation was observed in

both BURA condensates. It is concluded that the paving fume condensate was not carcinogenic under the test conditions and that the field-matched BURA fume condensate produced a weak tumor response compared to the lab generated sample.

Cui, P., et al. (2020). "VOC emissions from asphalt pavement and health risks to construction workers." Journal of Cleaner Production 244: 118757.

Hot Mix Asphalt (HMA) is used in the construction of highway roads, parking lots and other pavement repairs in the US and worldwide. During asphalt pavement installation, a large amount of asphalt fume containing volatile organic compounds (VOCs) is emitted, causing potential health risks to construction workers. The field data investigation in this paper reports the concentration of VOCs around the workers on site using the Photo Ionization Detection (PID) device. Additionally, this paper presents a health risk evaluation model based on the Monte Carlo simulation to assess the carcinogenic and non-carcinogenic risks of workers during pavement construction. More specifically, distribution and sensitivity analyses illustrate the factors that pose the greatest health risks caused by certain VOCs. The study calls for better health risk controls by targeting the emission sources, propagating pathways, and individual receptors of the VOCs to protect workers' health during pavement construction. This paper contributes to the knowledge of VOCs generated from HMA and the potential health risks to construction workers, as well as suggests the implementation of new requirements for pavement construction codes and safety regulations.

Freeman, J. J., et al. (2011). "Asphalt fume dermal carcinogenicity potential: II. Initiation-promotion assay of Type III built-up roofing asphalt." Regul Toxicol Pharmacol 61(1): 17-22.

Clark et al. (accepted for publication) reported that a sample of field-matched fume condensate from a Type III built-up roofing asphalt (BURA) resulted in a carcinogenic response in a mouse skin bioassay, with relatively few tumor-bearing animals, long tumor latency and chronic skin irritation. This mouse skin initiation/promotion study was conducted to assess possible mechanisms, i.e., genotoxic initiation vs. tumor promotion subsequent to repeated skin injury and repair. The same Type III BURA fume condensate sample was evaluated in groups of 30 male Crl:CD1(R) mice by skin application twice per week (total dose of 50 mg/week) for 2 weeks during the initiation phase and for 26 weeks during the promotion phase. Positive control substances were 7,12-dimethylbenz(a)anthracene (DMBA, 50 mug applied once) as an initiator and 12-O-tetradecanoyl-13-acetate (TPA, 5 mug, applied twice weekly) during the promotion phase. During the 6 months of study with the asphalt fume condensate, eight skin masses were observed when tested for initiation, five of which were confirmed microscopically to be benign squamous cell papillomas. Only two papillomas were observed when tested for promotion. There was no apparent relationship between skin irritation and tumor development in this study. These results are more indicative of genotoxicity rather than a non-genotoxic mode of action.

Freund, A., et al. (2012). "Submicron particle monitoring of paving and related road construction operations." J Occup Environ Hyg 9(5): 298-307.

This study identified activities and sources that contribute to ultrafine and other submicron particle exposure that could trigger respiratory symptoms in highway repair workers. Submicron particle monitoring was conducted for paving, milling, and pothole repair operations in a major metropolitan area where several highway repair workers were identified as symptomatic for respiratory illness following exposures at the 2001 World Trade Center disaster site. Exposure assessments were conducted for eight trades involved in road construction using

a TSI P-Trak portable condensation particle counter. Direct readings near the workers' breathing zones and observations of activities and potential sources were logged on 7 days on 27 workers using four different models of pavers and two types of millers. Average worker exposure levels ranged from 2 to 3 times background during paving and from 1 to 4 times background during milling. During asphalt paving, average personal exposures to submicron particulates were 25,000-60,000, 28,000-70,000, and 23,000-37,000 particles/ cm(3) for paver operators, screed operators, and rakers, respectively. Average personal exposures during milling were 19,000-111,000, 28,000-81,000, and 19,000 particles/cm(3) for the large miller operators, miller screed operators, and raker, respectively. Personal peak exposures were measured up to 467,000 and 455,000 particles/cm(3) in paving and milling, respectively. Several sources of submicron particles were identified. These included the diesel and electric fired screed heaters; engine exhaust from diesel powered construction vehicles passing by or idling; raking, dumping, and paving of asphalt; exhaust from the hotbox heater; pavement dust or fumes from milling operations, especially when the large miller started and stopped; and secondhand cigarette smoke. To reduce the potential for health effects in workers, over 40 recommendations were made to control exposures, including improved maintenance of paver ventilation systems; diesel fume engineering controls; reduced idling; provision of cabs for the operators; and improved dust suppression systems on the milling machine.

Herrick, R. F., et al. (2007). "Physical and chemical characterization of asphalt (bitumen) paving exposures." J Occup Environ Hyg 4 Suppl 1: 209-216.

The purpose of this research was to characterize the physical and chemical properties of asphalt (bitumen) fume and vapor in hot mix asphalt roadway paving operations. Area and personal air samples were taken using real-time equipment and extractive sampling and analytical methods to determine worker asphalt exposure, as well as to characterize the properties of the particulate and vapor phase components. Analysis of personal inhalation and dermal samples by gas chromatography/mass spectroscopy showed that the polycyclic aromatic hydrocarbon profile is dominated by compounds with molecular weights below 228, and that substituted and heterocyclic polycyclic aromatic hydrocarbons comprised approximately 71% of the detectable mass concentration (vapor and particulate combined). Principal components analysis shows that the polycyclic aromatic hydrocarbons with molecular weights greater than 190 are the driving force behind the polycyclic aromatic compound exposures measured for the dermal and particulate phases; there was no clear trend for the vapor phase Most of the aerosol particles are fine (mass median aerodynamic diameter 1.02 microm; count median diameter 0.24 microm).

Hill, R. H., et al. (2015). "Quantification of Total Particulate Matter and Benzene-Soluble Fraction Inhalation Exposures in Roofing Workers Performing Tear-off Activities." J Occup Environ Hyg 12(7): 450-457.

Asphalt shingle removal (tear-off) from roofs is a major job task for an estimated 174,000 roofers in the United States. However, a literature search showed that there are no published studies that characterize worker inhalation exposures to asphalt particulates during shingle tear-off. To begin to fill this gap, the present study of inhalation exposures of roofers performing asphalt shingle tear-off was undertaken. The airborne agents of interest were total particulate matter (TP) and organic particulates measured as the benzene-soluble fraction (BSF) of total particulate. The study's objectives were to measure the personal breathing zone (PBZ) exposures of roofing tear-off workers to BSF and TP; and to assess whether these PBZ

exposures are different from ambient levels.Task-based PBZ samples (typical duration 1-5 hours) were collected during asphalt shingle tear-off from roofs near Houston, Texas and Denver, Colorado. Samples were analyzed for TP and BSF using National Institute of Occupational Safety and Health (NIOSH) Method 5042. As controls, area samples (typical duration 3-6 hours) were collected on the ground near the perimeter of the tear-off project Because of the presence of significant sources of inorganic particulates in the work environment, emphasis was placed on the BSF data. No BSF exposure higher than 0.25 mg/m3 was observed, and 69% of the PBZ samples were below the limit of detection (LOD). Due to unforeseen confounding, however, statistical comparisons of on-the-roof PBZ samples with on-the-ground area samples posed some special challenges. This confounding grew out of the interaction of three factors: statistical censoring from the left; the strong inverse correlation between LOD concentration and sampling duration; and variation in sampling durations between on-the-ground area samples and on-the-roof PBZ samples. A general linear model analysis of variance (GLM-ANOVA) was applied to help address the confounding. The results of this analysis indicate that personal sample BSF results were not statistically significantly different from the background/area samples. © Copyright 2015 JOEH, LLC.

Hong, O., et al. (2014). "The association between occupational exposures and cigarette smoking among operating engineers." Archives of Environmental and Occupational Health 69(3): 172-179.

The purpose of this study was to determine the relationship between occupational exposures and cigarette smoking among operating engineers. A cross-sectional survey was conducted with operating engineers (N =412) from a midwestern state in the United States. The survey included validated questions on cigarette smoking, occupational exposures, demographics, comorbidities, and health behaviors. About 35% were current smokers. Those exposed to asphalt fumes, heat stress, concrete dust, and welding fumes were less likely to smoke (odds ratio [OR] = .79, 95% confidence interval [CI]: .64-.98). Other factors associated with smoking included younger age (OR = .97, 95% CI: .94-.99), problem drinking (OR = 1.07, 95% CI: 1.03-1.12), lower Body Mass Index (OR = .95, 95% CI: .90-.99), and being separated/widowed/divorced (OR = 2.24, 95% CI: 1.19-4.20). Further investigation is needed for better understanding about job-specific exposure patterns and their impact on cigarette smoking among operating engineers. © 2014 Taylor & Francis Group, LLC.

Kriech, A. J., et al. (2010). "Side-by-side comparison of field monitoring methods for hot bitumen emission exposures: the German IFA Method 6305, U.S. NIOSH Method 5042, and the Total Organic Matter Method." J Occup Environ Hyg 7(12): 712-725.

Field studies were conducted at paving and roofing sites to compare the German Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) Fourier transform infrared spectroscopy method 6305 with the National Institute for Occupational Science and Health (NIOSH) benzene soluble fraction method 5042 plus total organic matter. Sampling using both methods was performed in multiple bitumen-related workplace environments. To provide comparable data all samplings were performed in parallel, and the analytical data were related to the same representative bitumen condensate standard. An outline of the differences between the sampling and analytical methods is provided along with comparative data obtained from these site investigations. A total of 55 bitumen paving sampler pairs were reported and statistical comparisons made using the 35 pairs of detectable data. First, the German inhalable aerosol data and the NIOSH benzene soluble fraction (BSF) method

showed a correlation coefficient of R(2)= 0.88 (y((BSF))= 0.60 x((aerosol))). Second, the aerosol data compared with total particulate matter (TPM) show a R(2) of 0.83 (y((TPM))= 1.01 x((aerosol))). Finally, total organic matter (TOM) and "aerosol + vapor" data yielded a R(2) of 0.78 (y((TOM))= 0.44 x((aerosol+vapor))). Twenty-nine pairs of roofing data were also collected; 37% were below the limit of detection. When comparing the TOM data with the aerosol + vapor data, using the 13 of 29 pairs where both samplers showed detectable results, the relationship was y((TOM))= 0.74 x((aerosol+vapor)) (R(2)= 0.91). The slopes within these equations provide predictive factors between these sampling and analysis methods; intended for use with large sets of data, they are not applicable to single point measurements.

Kriech, A. J., et al. (2004). "Evaluation of worker exposure to asphalt roofing fumes: influence of work practices and materials." J Occup Environ Hyg 1(2): 88-98.

A field study was conducted on 42 asphalt-roofing workers at 7 built-up roofing sites across the United States. Sixteen out of 42 samples show levels of exposure to asphalt fumes that exceed the current American Conference of Governmental Industrial Hygienists' (ACGIH)-recommended threshold limit value of 0.5 mg/m(3) as benzene extractable inhalable particulate. Statistically, the geometric mean of all 42 worker samples was 0.27 mg/m(3) (geometric standard deviation = 3.40), the average was 0.70 mg/m(3) (standard deviation = 1.69) and the median value was 0.24 mg/m(3). The impact of work practices is discussed including the use of a novel product that uses a polymer skin to reduce fumes from built up roofing asphalt. Its use resulted in a reduction of benzene soluble matter (BSM) of >70%. Other testing measures utilized included total particulate matter, total organic matter, simulated distillation, and fluorescence analysis. Additionally, a controlled pilot study using 16 kettle-area and 16 worker samples clearly showed that when the temperature of the kettle was reduced by 28 degrees C, there was a 38-59% reduction in fume exposure and a 54% reduction in fluorescence with standard asphalts. Reduction of BSM exposures using fuming-suppressed asphalt was also confirmed during this pilot plant study (81-92%), with fluorescence lowered by 88%. Confounding agents such as roof tear-off materials were also analyzed and their contribution to worker exposure is discussed.

Kriech, A. J., et al. (2004). "Total versus inhalable sampler comparison study for the determination of asphalt fume exposures within the road paving industry." J Environ Monit 6(10): 827-833.

Exposure to asphalt fumes has a threshold limit value (TLV of 0.5 mg m(-3) (benzene extractable inhalable particulate) as recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). This reflects a recent change (2000) whereby two variables are different from the previous recommendation. First is a 10-fold reduction in quantity from 5 mg m(-3) to 0.5 mg m(-3). Secondly, the new TLV specifies the "inhalable" fraction as compared to what is presumed to be total particulate. To assess the impact of these changes, this study compares the differences between measurements of paving asphalt fume exposure in the field using an "inhalable" instrument versus the historically used 'total' sampler. Particle size is also examined to assist in the understanding of the aerodynamic collection differences as related to asphalt fumes and confounders. Results show that when exposures are limited to asphalt fumes, a 1:1 relationship exists between samplers, showing no statistically significant differences in benzene soluble matter (BSM). This means that for the asphalt fume ACGIH TLV, the 'total' 37-mm sampler is an equivalent method to the "inhalable" method, referred to as IOM (Institute of Occupational Medicine), and should be acceptable for use

against the TLV. However, the study found that when confounders (dust or old asphalt millings) are present in the workplace, there can be significant differences between the two samplers' reported exposure. The ratio of IOM/Total was 1.37 for milling asphalt sites, 1.41 for asphalt paving over granular base, and 1.02 for asphalt over asphalt pavements.

Law, B. F., et al. (2006). "Characterization of laboratory simulated road paving-like asphalt by high-performance liquid chromatography and gas chromatography-mass spectrometry." J Occup Environ Hyg 3(7): 343-350.

Prolonged, extensive exposure to asphalt fume has been associated with several adverse health effects. Inhaled polycyclic aromatic hydrocarbons (PAHs) from asphalt fume exposure are of concern. The objective of this study was to characterize both qualitative and quantitative differences between fumes generated at 150 degrees C and 180 degrees C using a well-controlled laboratory road paving fume generation system. Fumes were characterized by total volatile and particulate concentration, simulated boiling point profile, and specific PAH content. The mean concentrations of the volatile fractions generated at 180 degrees C and 150 degrees C were 23.3 mg/m3 and 11.2 mg/m3, respectively, demonstrating a statistically significant shift in concentration. The mean concentrations of the particulate fractions generated at 180 degrees C and 150 degrees C were 42.4 mg/m3 and 28.0 mg/m3, respectively. The simulated boiling point profile did not show a significant qualitative difference between the fumes generated at the two temperatures. Naphthalene, acenaphthene, fluorene, phenanthrene, fluoranthene, pyrene, and chrysene were identified and quantified from the fumes.

Lindberg, H. K., et al. (2008). "Genotoxic effects of fumes from asphalt modified with waste plastic and tall oil pitch." Mutat Res 653(1-2): 82-90.

As the use of recycled materials and industrial by-products in asphalt mixtures is increasing, we investigated if recycled additives modify the genotoxicity of fumes emitted from asphalt. Fumes were generated in the laboratory at paving temperature from stone-mastic asphalt (SMA) and from SMA modified with waste plastic (90% polyethylene, 10% polypropylene) and tall oil pitch (SMA-WPT). In addition, fumes from SMA, SMA-WPT, asphalt concrete (AC), and AC modified with waste plastic and tall oil pitch (AC-WPT) were collected at paving sites. The genotoxicity of the fumes was studied by analysis of DNA damage (measured in the comet assay) and micronucleus formation in human bronchial epithelial BEAS 2B cells in vitro and by counting mutations in Salmonella typhimurium strains TA98 and YG1024. DNA damage was also assessed in buccal leukocytes from road pavers before and after working with SMA, SMA-WPT, AC, and AC-WPT. The chemical composition of the emissions was analysed by gas chromatography/mass spectrometry. The SMA-WPT fume generated in the laboratory induced a clear increase in DNA damage in BEAS 2B cells without metabolic activation. The laboratory-generated SMA fume increased the frequency of micronucleated BEAS 2B cells without metabolic activation. None of the asphalt fumes collected at the paving sites produced DNA damage with or without metabolic activation. Fumes from SMA and SMA-WPT from the paving sites increased micronucleus frequency without metabolic activation. None of the asphalt fumes studied showed mutagenic activity in Salmonella. No statistically significant differences in DNA damage in buccal leukocytes were detected between the pre- and post-shift samples collected from the road pavers. However, a positive correlation was found between DNA damage and the urinary metabolites of polycyclic aromatic hydrocarbons (PAHs) after work shift, which suggested an association between

occupational exposures during road paving and genotoxic effects. Our results indicate that fumes from SMA and SMA-WPT contain direct-acting genotoxic components.

Liu, B. and C. Jia (2016). "Effects of profession on urinary PAH metabolite levels in the US population." Int Arch Occup Environ Health 89(1): 123-135.

Purpose: Although exposure to polycyclic aromatic hydrocarbons (PAHs) is common in both environmental and occupational settings, few studies have compared PAH exposure among people with different professions. The purpose of this study was to investigate the variations in recent PAH exposure among different occupational groups over time using national representative samples. Method: The study population consisted of 4162 participants from the 2001 to 2008 National Health and Nutrition Examination Survey, who had both urinary PAH metabolites and occupational information. Four corresponding monohydroxy-PAH urine metabolites: naphthalene (NAP), fluorene (FLUO), phenanthrene (PHEN), and pyrene (PYR) among seven broad occupational groups were analyzed using weighted linear regression models, adjusting for creatinine levels, sociodemographic factors, smoking status, and sampling season. Results: The overall geometric mean concentrations of NAP, FLUO, PHEN, and PYR were 6927, 477, 335, and 87 ng/L, respectively. All four PAH metabolites were elevated in the “extractive, construction, and repair (ECR)” group, with 21–42 % higher concentrations than those in the reference group of “management.” Similar trends were seen in the “operators, fabricators, and laborers (OFL)” group for FLUO, PHEN, and PYR. In addition, both “service” and “support” groups had elevated FLUO. Significant ($p < 0.001$) upward temporal trends were seen in NAP and PYR, with an approximately 6–17 % annual increase, and FLUO and PHEN remained relatively stable. Race and socioeconomic status show independent effects on PAH exposure. Conclusions: Heterogeneous distributions of urinary PAH metabolites among people with different job categories exist at the population level. The upward temporal trends in NAP and PYR warrant reduction in PAH exposure, especially among those with OFL and ECR occupations. © 2015, Springer-Verlag Berlin Heidelberg.

McClean, M. D., et al. (2004). "Inhalation and dermal exposure among asphalt paving workers." Ann Occup Hyg 48(8): 663-671.

The primary objective of this study was to identify determinants of inhalation and dermal exposure to polycyclic aromatic compounds (PACs) among asphalt paving workers. The study population included three groups of highway construction workers: 20 asphalt paving workers, as well as 12 millers and 6 roadside construction workers who did not work with hot-mix asphalt. During multiple consecutive work shifts, personal air samples were collected from each worker's breathing zone using a Teflon filter and cassette holder connected in series with an XAD-2 sorbent tube, while dermal patch samples were collected from the underside of each worker's wrist. All exposure samples were analyzed for PACs, pyrene and benzo[a]pyrene. Inhalation and dermal PAC exposures were highest among asphalt paving workers. Among paving workers, inhalation and dermal PAC exposures varied significantly by task, crew, recycled asphalt product (RAP) and work rate (inhalation only). Asphalt mix containing high RAP was associated with a 5-fold increase in inhalation PAC exposures and a 2-fold increase in dermal PAC exposure, compared with low RAP mix. The inhalation PAC exposures were consistent with the workers' proximity to the primary source of asphalt fume (paver operators > screedmen > rakers > roller operators), such that the adjusted mean exposures among paver operators (5.0 microg/m3, low RAP; 24 microg/m3, high RAP) were 12 times higher than among roller operators (0.4 microg/m3, low RAP; 2.0 microg/m3, high RAP). The dermal PAC

exposures were consistent with the degree to which the workers have actual contact with asphalt-contaminated surfaces (rakers > screedmen > paver operators > roller operators), such that the adjusted mean exposures among rakers (175 ng/cm2, low RAP; 417 ng/cm2, high RAP) were approximately 6 times higher than among roller operators (27 ng/cm2, low RAP; 65 ng/cm2, high RAP). Paving task, RAP content and crew were also found to be significant determinants of inhalation and dermal exposure to pyrene. The effect of RAP content, as well as the fact that exposures were higher among paving workers than among millers and roadside construction workers, suggests that the PAC and pyrene exposures experienced by these paving workers were asphalt-related.

McClean, M. D., et al. (2004). "Urinary 1-hydroxypyrene and polycyclic aromatic hydrocarbon exposure among asphalt paving workers." Ann Occup Hyg 48(6): 565-578.

OBJECTIVES: Using urinary 1-hydroxypyrene (1-OHP) as a measure of total absorbed dose, the primary objective of this study was to evaluate the total effect of inhalation and dermal PAH exposures while considering other factors such as age, body mass index and smoking that may also have a significant effect on urinary 1-OHP. METHODS: The study population included two groups of highway construction workers: 20 paving workers and 6 milling workers. During multiple consecutive workshifts, personal air and dermal samples were collected from each worker and analyzed for pyrene. During the same work week, urine samples were collected pre-shift, post-shift and at bedtime each day and analyzed for 1-OHP. Distributed lag models were used to evaluate the independent effect of inhalation and dermal exposures that occurred at each of several preceding exposure periods and were used to identify the relevant period of influence for each pathway. RESULTS: The paving workers had inhalation (mean 0.3 micro g/m(3)) and dermal (5.7 ng/cm(2)) exposures to pyrene that were significantly higher than the milling workers. At pre-shift on Monday morning, following a weekend away from work, the pavers and millers had the same mean baseline urinary 1-OHP level of 0.4 micro g/g creatinine. The mean urinary 1-OHP levels among pavers increased significantly from pre-shift to post-shift during each work day, while the mean urinary 1-OHP levels among millers varied little and remained near the baseline level throughout the study period. Among pavers there was a clear increase in the pre-shift data during the work week, such that the average pre-shift level on day 4 (1.4 micro g/g creatinine) was 3.5 times higher than the average pre-shift results on day 1 (0.4 micro g/g creatinine). The results of the distributed lag model indicated that the impact of dermal exposure was approximately eight times the impact of inhalation exposure. Furthermore, dermal exposure that occurred during the preceding 32 h had a statistically significant effect on urinary 1-OHP, while the effect of inhalation exposure was not significant. CONCLUSIONS: We found that distributed lag models are a valuable tool for analyzing longitudinal biomarker data and our results indicate that dermal contact is the primary route of exposure to PAHs among asphalt paving workers. An exposure assessment of PAHs that does not consider dermal exposure may considerably underestimate cumulative exposure and control strategies aimed at reducing occupational exposure to asphalt-related PAHs should include an effort to reduce dermal exposure.

McClean, M. D., et al. (2007). "Dermal exposure and urinary 1-hydroxypyrene among asphalt roofing workers." J Occup Environ Hyg 4 Suppl 1: 118-126.

The primary objective of this study was to identify significant determinants of dermal exposure to polycyclic aromatic compounds (PACs) among asphalt roofing workers and use urinary 1-hydroxyprene (1-OHP) measurements to evaluate the effect of dermal exposure on

total absorbed dose. The study population included 26 asphalt roofing workers who performed three primary tasks: tearing off old roofs (tear-off), putting down new roofs (put-down), and operating the kettle at ground level (kettle). During multiple consecutive work shifts (90 workerdays), dermal patch samples were collected from the underside of each worker's wrists and were analyzed for PACs, pyrene, and benzo(a)pyrene (BAP). During the same work week, urine samples were collected at pre-shift, post-shift, and bedtime each day and were analyzed for 1-OHP (205 urine samples). Linear mixed effects models were used to evaluate the dermal measurements for the purpose of identifying important determinants of exposure, and to evaluate urinary 1-OHP measurements for the purpose of identifying important determinants of total absorbed dose. Dermal exposures to PAC, pyrene, and BAP were found to vary significantly by roofing task (tear-off > put-down > kettle) and by the presence of an old coal tar pitch roof (pitch > no pitch). For each of the three analytes, the adjusted mean dermal exposures associated with tear-off (812 ng PAC/cm2, 14.9 ng pyrene/cm2, 4.5 ng BAP/cm2) were approximately four times higher than exposures associated with operating the kettle (181 ng PAC/cm2, 4.1 ng pyrene/cm2, 1.1 ng BAP/cm2). Exposure to coal tar pitch was associated with a 6-fold increase in PAC exposure ($p = 0.0005$), an 8-fold increase in pyrene exposure ($p < 0.0001$), and a 35-fold increase in BAP exposure ($p < 0.0001$). Similarly, urinary 1-OHP levels were found to be significantly higher on days when an old pitch roof was removed, accounting for a 3.7-fold difference at pre-shift ($p = 0.01$), a 5.0-fold difference at post-shift ($p = 0.004$), and a 7.2-fold difference at bedtime ($p = 0.002$). The pyrene measurements obtained during the work shift were found to be strongly correlated with urinary 1-OHP measurements obtained at the end of that shift ($r = 0.8$, $p < 0.001$) as well as at bedtime ($r = 0.7$, $p < 0.001$). Ultimately, the results of a distributed lag model indicated that dermal exposure during the preceding 40 hours had a statistically significant effect on urinary 1-OHP. The presence of coal tar pitch was the primary determinant of dermal exposure, particularly for exposure to BAP. However, the task-based differences that were observed while controlling for pitch suggest that exposure to asphalt also contributes to dermal exposures. We found that dermal exposure was a significant determinant of total absorbed dose, suggesting that control strategies aimed at reducing occupational exposure to PACs should include an effort to minimize dermal exposure.

McClean, M. D., et al. (2007). "DNA adducts among asphalt paving workers." Ann Occup Hyg 51(1): 27-34.

OBJECTIVE: Asphalt is used extensively in the highway construction industry and contains a complex mixture of polycyclic aromatic hydrocarbons, some of which are known or suspected to be human carcinogens. Though numerous epidemiologic studies have described an excess cancer risk among asphalt workers, a causal relationship has not been established. Accordingly, the primary objective of this study was to use DNA adducts as a biomarker of biologically effective dose and determine whether DNA damage resulted from occupational exposure to asphalt among paving workers. METHODS: Over a 12 month period, four peripheral blood samples (spring, summer, fall and winter) were obtained from 49 asphalt paving workers (169 samples) and 36 non-paving construction workers (103 samples). The spring, summer and fall samples were collected during the work-season, whereas the winter samples were collected during the off-season (due to the seasonality of paving work). Mononuclear white blood cells were isolated and analyzed for DNA adducts via the (32)P-postlabeling assay and generalized linear models were used to evaluate the DNA adduct data. RESULTS: Among paving workers during the work-season, DNA adducts increased during each day of the workweek such that mean adduct levels were lowest on Mondays (3 adducts per

10(10) nucleotides) and highest on Fridays (46 adducts per 10(10) nucleotides). Additionally, a 3-fold difference in adduct burden was observed by paving task such that mean adduct levels were lowest among roller operators (7 adducts per 10(10) nucleotides) and highest among screedmen (23 adducts per 10(10) nucleotides). Using adducts as a measure of biologically effective dose, these findings (weekday trend and task-based differences) were consistent with a previous evaluation of absorbed dose in the same population. Adduct levels were not, however, higher among paving workers than among non-pavers. Adducts were also highest during the winter months, suggestive of a seasonal effect that has been observed in previous studies. CONCLUSION: These findings indicate that adduct burden increased throughout the workweek among paving workers, suggesting that DNA damage may be associated with occupational exposure to hot-mix asphalt. However, the lack of contrast with non-paving workers, as well as the seasonal variation warrants additional investigation.

Methner, M. M. (2000). "Identification of potential hazards associated with new residential construction." Appl Occup Environ Hyg 15(2): 189-192.

There were several advantages and limitations of this observational study. The most important advantage of this study was the opportunity to observe residential construction workers performing their jobs. By observing work practices, valuable information was gathered about specific trades and their potential exposure to various chemical and physical agents. This information will be useful in guiding subsequent exposure assessments. Probably the greatest limitation of this study was the lack of participation by homebuilders. Ideally, observations of construction processes would have been more objective if the study included the participation of more than one homebuilder. Aside from one worker who was observed to wear safety glasses, leather gloves, and a dust mask, virtually no personal protective equipment (PPE) was observed onsite. Often small contractors do not have the financial resources necessary to procure the appropriate PPE and issue these items to the workers. Based on hazard prevalence, professional judgement, and the degree of hazardous product use, potential exposures that warrant quantitative sampling efforts during Phase 2 of this study are: bulldozer/backhoe operators--noise, vibration, diesel exhaust; concrete workers--naphtha, mineral spirits, Portland cement; asphalt workers--petroleum hydrocarbons, asphalt, mineral spirits; plumbers--methylethyl ketone, acetone, tetrahydrofuran, cyclohexanone; drywall finishers--total and respirable dust, hexane, acetone; painters--ethylene glycol, VOCs; masons--dust (during the preparation of mortar); floor preparation technicians--total and respirable dust; and ceramic tile installers--toluene, naphtha, silica (from grout powder).

Mickelsen, R. L., et al. (2006). "Status of worker exposure to asphalt paving fumes with the use of engineering controls." Environ Sci Technol 40(18): 5661-5667.

Since 1996, industry, labor, and government have partnered to minimize workers' exposure to asphalt fumes using engineering controls. The objective of this study was to determine the use after some years of experience and to benchmark the effectiveness of the engineering controls as compared to the current exposure limits. To accomplish this objective, the current highway class pavers equipped with controls to reduce asphalt fumes, occupational exposure levels, and ventilation flow rates were monitored, and a user acceptance survey was conducted. Personal breathing-zone sampling was administered to determine concentrations of total particulate matter (TPM) and benzene soluble matter (BSM). Personal monitoring of workers yielded a BSM arithmetic mean of 0.13 mg/m3 (95% confidence limits (0.07, 0.43) mg/m3). All site average worker BSM values are below the American Conference of

Governmental Industrial Hygienists (ACGIH) adopted threshold limit value (TLV) time weighted average (TWA) of 0.5 mg/m3 as benzene soluble inhalable particulate, although five sites contained 95% confidence limits slightly above the ACGIH TLV. The TPM arithmetic mean was 0.35 mg/m3 (95% confidence limits (0.27, 0.69) mg/m3). All sites showed average worker and area TPM values below NIOSH's recommended exposure limit for asphalt fumes (5 mg/m3, 15 min). One screed area sample and one operator area sample were also taken each day. Area samples followed a similar pattern to the worker breathing zone samples, but were generally slightly higher in TPM and BSM concentration. The effect of work practices and application temperatures appears to have an impact on the ability of the engineering controls to keep exposure below the TLV for BSM. To gain a better understanding of the aerodynamic properties of asphalt fumes, particle size and airborne concentrations were also monitored using a TSI model 3320 aerodynamic particle sizer spectrometer. The geometric mean particle size was between 0.64 and 0.98 micrometers for the worker breathing zone samples, with a geometric mean of 0.73 micrometers for all sites. Total airborne concentrations were typically higher for the asphalt fume exposed groups than for the background samples. During high fume events, four 15-minute samples were taken each day. Only one 15-minute sample was above the limit of quantification. Stack flow rates were measured, and results are discussed and compared to the manufacturers' nominal values. Survey results were generally positive, with recommendations discussed for continuous improvement.

Mundt, D. J., et al. (2009). "A review of changes in composition of hot mix asphalt in the United States." J Occup Environ Hyg 6(11): 714-725.

This review researched the materials, methods, and practices in the hot mix asphalt industry that might impact future exposure assessments and epidemiologic research on road paving workers. Since World War II, the U.S. interstate highway system, increased traffic volume, transportation speeds, and vehicle axle loads have necessitated an increase in demand for hot mix asphalt for road construction and maintenance, while requiring a consistent road paving product that meets state-specific physical performance specifications. We reviewed typical practices in hot mix asphalt paving in the United States to understand the extent to which materials are and have been added to hot mix asphalt to meet specifications and how changes in practices and technology could affect evaluation of worker exposures for future research. Historical documents were reviewed, and industry experts from 16 states were interviewed to obtain relevant information on industry practices. Participants from all states reported additive use, with most being less than 2% by weight. Crumb rubber and recycled asphalt pavement were added in concentrations approximately 10% per unit weight of the mix. The most frequently added materials included polymers and anti-stripping agents. Crumb rubber, sulfur, asbestos, roofing shingles, slag, or fly ash have been used in limited amounts for short periods of time or in limited geographic areas. No state reported using coal tar as an additive to hot mix asphalt or as a binder alternative in hot mix pavements for high-volume road construction. Coal tar may be present in recycled asphalt pavement from historical use, which would need to be considered in future exposure assessments of pavers. Changes in hot mix asphalt production and laydown emission control equipment have been universally implemented over time as the technology has become available to reduce potential worker exposures. This work is a companion review to a study undertaken in the petroleum refining sector that investigated current and historical use of additives in producing petroleum-derived asphalt cements.

Parker, C. M., et al. (2011). "Evaluation of reproductive/developmental and repeated dose (subchronic) toxicity and cytogenetic effects in rats of a roofing asphalt fume condensate by nose-only inhalation." Regul Toxicol Pharmacol 59(3): 445-453.

A Type III Built-up Roofing Asphalt (BURA) fume condensate was evaluated for subchronic systemic toxicity and reproductive/developmental toxicity screening in Wistar rats, by OECD protocol 422 and OECD cytogenetic protocol 474. Animals were exposed by nose-only inhalation to target concentrations of 30, 100 and 300 mg/m(3) total hydrocarbons (actual concentrations, 30.0, 100.1 and 297.3 mg/m(3)). The study was performed to assess potential hazards from asphalt fumes to which humans could be exposed during application. No adverse effects were seen for spermology, reproductive or developmental parameters or early postnatal development of offspring from day 1 to 4 postpartum. BURA fume condensate did not induce any significant increases in micronucleus frequency in polychromatic erythrocytes of rat bone marrow nor was neurobehavioral toxicity observed at any dose. Systemic effects were slight and seen at doses above those measured at work sites. The systemic NOAEC of 100 mg/m(3) for males was based on decreased body weight gain, food consumption and increased absolute and relative lung wet weight correlated with slight histological changes in the lung, primarily adaptive in nature at 300 mg/m(3). The female NOAEC of 30 mg/m(3) was based on a statistically significant increase in relative wet lung weight at higher doses, correlated with slight histopathologic effects in the lungs at the highest dose. However, no increase in relative lung weight was seen in breeding females at 100 mg/m(3).

Raghavendra, A., et al. (2016). "Laboratory and construction evaluation of Warm-mix asphalt." Journal of Materials in Civil Engineering 28(7).

Warm mix asphalt (WMA) describes various technologies that allow asphalt mixtures to be produced at lower temperatures as compared with hot mix asphalt (HMA). WMA technologies also offer improvements in workability, cost, and environmental sustainability, such as reduced fuel usage, greenhouse gas emissions, and wear and tear at plants, while enhancing worker health and safety conditions. The objective of this study was to quantify the laboratory performance of field-produced mixtures that utilize WMA technologies and to evaluate the influence of lowering the production temperature on the mixture properties in the field. To achieve this objective, three field projects across Louisiana were selected to provide eight mixtures for the evaluation of WMA technologies. Plant-produced mixtures were sampled and the laboratory performance of WMA mixtures and conventional HMA was evaluated. Further, the characteristics of WMA mixtures were compared with conventional HMA mixtures during production and construction. Based on the results of the experimental program, it was concluded that there was no difference in the rutting performance of WMA compared with HMA. In addition, the use of WMA technologies improved asphalt mixture fracture resistance. With respect to moisture susceptibility, the tensile strength ratio (TSR) of the WMA mixtures was comparable to the conventional HMA in two projects; however, it was lower than the TSR criterion of 80% in the third project. During production, while the moisture content in WMA was slightly higher than the conventional mixtures, both mixture types met Louisiana's specifications (with moisture content less than 0.3%). Further, asphalt absorption was not statistically different between HMA and WMA. During paving, the temperature of the mat was distinctly lower for WMA than for HMA. With respect to the compaction effort, there seemed to be no discernible difference in the compaction effort required for HMA and WMA. In addition, the WMA mixtures were able to meet the minimum specification requirement of 92% density in most of the cases. © 2016 American Society of Civil Engineers.

Rhomberg, L. R., et al. (2015). "Quantitative cancer risk assessment for occupational exposures to asphalt fumes during built-up roofing asphalt (BURA) operations." Crit Rev Toxicol 45(10): 873-918.

The International Agency for Research on Cancer qualitatively characterized occupational exposure to oxidized bitumen emissions during roofing as probably carcinogenic to humans (Group 2A). We examine chemistry, exposure, epidemiology and animal toxicity data to explore quantitative risks for roofing workers applying built-up roofing asphalt (BURA). Epidemiology studies do not consistently report elevated risks, and generally do not have sufficient exposure information or adequately control for confounders, precluding their use for dose-response analysis. Dermal carcinogenicity bioassays using mice report increased tumor incidence with single high doses. In order to quantify potential cancer risks, we develop time-to-tumor model methods [consistent with U.S. Environmental Protection Agency (EPA) dose-response analysis and mixtures guidelines] using the dose-time-response shape of concurrent exposures to benzo[a]pyrene (B[a]P) as concurrent controls (which had several exposure levels) to infer presumed parallel dose-time-response curves for BURA-fume condensate. We compare EPA relative potency factor approaches, based on observed relative potency of BURA to B[a]P in similar experiments, and direct observation of the inferred BURA dose-time-response (scaled to humans) as means for characterizing a dermal unit risk factor. We apply similar approaches to limited data on asphalt-fume inhalation and respiratory cancers in rats. We also develop a method for adjusting potency estimates for asphalts that vary in composition using measured fluorescence. Overall, the various methods indicate that cancer risks to roofers from both dermal and inhalation exposure to BURA are within a range typically deemed acceptable within regulatory frameworks. The approaches developed may be useful in assessing carcinogenic potency of other complex mixtures of polycyclic aromatic compounds.

Rhomberg, L. R., et al. (2018). "A bounding quantitative cancer risk assessment for occupational exposures to asphalt emissions during road paving operations." Crit Rev Toxicol 48(9): 713-737.

The International Agency for Research on Cancer recently classified straight-run bitumens and associated emissions during road paving as possibly carcinogenic to humans (Group 2B), owing to potential exposures to polycyclic aromatic hydrocarbons. We examine existing chemistry, exposure, epidemiology, and animal toxicity data to explore quantitative cancer risk implications for paving workers exposed to asphalt emissions from the data used in identifying this qualitative hazard. Epidemiology studies show no consistent cancer risk elevation. One skin-painting mouse study of paving asphalt emission condensate found a single tumor at only the highest tested dose, as did one rat inhalation study. These studies were used to develop an upper bound on possible carcinogenic potency of emissions that are inhaled or dermally deposited. Extending earlier work on roofing asphalt, we conducted time-to-tumor modeling using the dose-time-response shape for several dose levels of benzo[a]pyrene (B[a]P) in concurrent bioassay controls to infer presumed parallel dose-time-response curves for paving-asphalt-emission condensate. In addition, we developed a scientific rationale, based on general scaling considerations and on dermal uptake, for the chosen means to scale observed dermal cancer potencies in mice to apply to dermal exposures in humans. The results indicate that paving asphalt emissions have a reduced dermal cancer potency compared to roofing asphalt, consistent with the lower levels of the multi-ringed PAHs implicated in cancer risks. Based on existing occupational exposure studies, cancer risks to pavers from both dermal and

inhalation exposure to asphalt emissions is within a range typically acceptable within regulatory frameworks.

Schreiner, C. A. (2011). "Review of mechanistic studies relevant to the potential carcinogenicity of asphalts." Regul Toxicol Pharmacol 59(2): 270-284.

Heating of asphalts to facilitate use in paving and roofing applications produces fumes containing polycyclic aromatic compounds (PAC). Regulatory organizations have suggested asphalt fumes of concern to humans due to possible carcinogenic effects but data are inadequate to classify. Two-year rodent inhalation studies and recent European epidemiology research have shown that asphalt fume alone does not pose a carcinogenic risk to humans. Dermal exposure to asphalt fume condensate have produced skin tumors in mouse skin painting studies but no skin cancer studies in humans have been reported occupationally. Mechanistic research explores underlying processes to assess relevance of findings in animals to humans. DNA adducts are useful as biological dosimeters of exposure, but DNA repair processes, lack of correlation with more definitive genotoxic and cancer results in animals and humans limits reliability as a predictor of carcinogenic hazard. Inhibition of gap junction intercellular communication and stimulation of intracellular signaling by asphalt fume condensate can relate to tumor development. Up and down-regulation of expression in genes involved in the metabolism and action of asphalt fume demonstrates intrinsic activity at the cellular level but changes were inconsistent. The relationship of reported effects on the immune system to carcinogenesis is unclear. Overall, results of mechanistic studies provide insights into biological activity from asphalt fume exposure but compositional differences, level of human exposure and detoxification processes must be considered in translating these findings to cancer risk.

Schulte, P. A. (2007). "Gaps in scientific knowledge about the carcinogenic potential of asphalt/bitumen fumes." J Occup Environ Hyg 4 Suppl 1: 3-5.

Despite a relatively large body of published research, the potential carcinogenicity of asphalt/bitumen fumes is still a vexing question. Various uncertainties and gaps in scientific knowledge need to be addressed. These include uncertainties in chemistry, animal studies, and human studies. The chemistry of asphalt/bitumen fumes is complex and varies according to the source of the crude oil and the application parameters. The epidemiological studies, while showing weak evidence of lung cancer, are inconsistent and many confounding factors have not been addressed. Studies of animal exposure are also inconsistent regarding laboratory and field-generated fumes. There is a need for further human studies that address potential confounding factors such as smoking, diet, coal tar, and diesel exposures. Animal inhalation studies need to be conducted with asphalt/bitumen fumes that are chemically representative of roofing and paving fumes. Underlying all of this is the need for continued characterization of fumes so their use in animal and field studies can be properly assessed. Nonetheless, uncertainties such as these should not preclude appropriate public health actions to protect workers in the even that asphalt fumes are found to be a carcinogenic hazard.

Serdar, B., et al. (2012). "Biomarkers of exposure to polycyclic aromatic hydrocarbons (PAHs) and DNA damage: a cross-sectional pilot study among roofers in South Florida." BMJ Open 2(4).

OBJECTIVE: The main goal of this pilot study was to assess the technical and logistic feasibility of a future study. The research hypothesis is that occupational exposures to polycyclic aromatic hydrocarbons (PAHs) are associated with increased risk of DNA damage

among roofers who work with hot asphalt. DESIGN: This is a cross-sectional pilot study. SETTING: The study included roofers from four different construction sites in Miami-Dade County, Florida. PARTICIPANTS: 19 roofers were recruited (six Hispanics and 13 African-Americans, all male), all of whom were eligible (no history of cancer and no history of chronic diseases of kidneys or liver). All participants provided pre-shift samples and 18 provided post-shift samples. Samples of one participant were excluded from the final analyses as they were considered unreliable. RESULTS: Levels of urinary PAH metabolites increased during 6 h of work. Linear regression models of post-shift metabolites included their pre-shift levels, post-shift urinary creatinine levels (for models of 1-OHPyr and 9-OHPhe), and skin burn due to contact with hot asphalt (for models of 1-OHPyr and 1-OHNap). Pre-shift levels of urinary 8-OHdG were not associated with any of the variables considered. For post-shift levels of 8-OHdG, however, post-shift 1-OHPyr (95% CI 0.091 to 0.788) and use of protective gloves (95% CI -1.57 to -0.61) during work explained 86.8% of its variation. Overall, highest levels of urinary PAH metabolites and of 8-OHdG were observed among workers who reported having skin burn and who did not use gloves during work. CONCLUSIONS: Urinary 1-OHPyr is a promising predictor of oxidative DNA damage among roofers. Work-related skin burn and use of protective gloves appear to influence PAH exposure and DNA damage levels in this group, suggesting the importance of dermal absorption.

Sobus, J. R., et al. (2009). "Investigation of PAH biomarkers in the urine of workers exposed to hot asphalt." Ann Occup Hyg 53(6): 551-560.

Airborne emissions from hot asphalt contain mixtures of polycyclic aromatic hydrocarbons (PAHs), including several carcinogens. We investigated urinary biomarkers of three PAHs, namely naphthalene (Nap), phenanthrene (Phe), and pyrene (Pyr) in 20 road-paving workers exposed to hot asphalt and in 6 road milling workers who were not using hot asphalt (reference group). Our analysis included baseline urine samples as well as postshift, bedtime, and morning samples collected over three consecutive days. We measured unmetabolized Nap (U-Nap) and Phe (U-Phe) as well as the monohydroxylated metabolites of Nap (OH-Nap), Phe (OH-Phe), and Pyr (OH-Pyr) in each urine sample. In baseline samples, no significant differences in biomarker levels were observed between pavers and millers, suggesting similar background exposures. In postshift, bedtime, and morning urine samples, the high pairwise correlations observed between levels of all biomarkers suggest common exposure sources. Among pavers, levels of all biomarkers were significantly elevated in postshift samples, indicating rapid uptake and elimination of PAHs following exposure to hot asphalt (biomarker levels were not elevated among millers). Results from linear mixed-effects models of levels of U-Nap, U-Phe, OH-Phe, and OH-Pyr across pavers showed significant effects of work assignments with roller operators having lower biomarker levels than the other workers. However, no work-related effect was observed for levels of OH-Nap, apparently due to the influence of cigarette smoking. Biological half-lives, estimated from regression coefficients for time among pavers, were 8 h for U-Phe, 10 h for U-Nap, 13 h for OH-Phe and OH-Pyr, and 26 h for OH-Nap. These results support the use of U-Nap, U-Phe, OH-Phe, and OH-Pyr, but probably not OH-Nap, as short-term biomarkers of exposure to PAHs emanating from hot asphalt.

Sobus, J. R., et al. (2010). "Biomarker variance component estimation for exposure surrogate selection and toxicokinetic inference." Toxicol Lett 199(3): 247-253.

Biomarkers are useful exposure surrogates given their ability to integrate exposures through all routes and to reflect interindividual differences in toxicokinetic processes. Also, biomarker concentrations tend to vary less than corresponding environmental measurements, making them less-biasing surrogates for exposure. In this article, urinary PAH biomarkers (namely, urinary naphthalene [U-Nap]; urinary phenanthrene [U-Phe]; 1-hydroxypyrene [1-OH-Pyr]; and 1-, (2+3)-, 4-, and 9-hydroxyphenanthrene [1-, (2+3)-, 4-, and 9-OH-Phe]) were evaluated as surrogates for exposure to hot asphalt emissions using data from 20 road-paving workers. Linear mixed-effects models were used to estimate the within- and between-person components of variance for each urinary biomarker. The ratio of within- to between-person variance was then used to estimate the biasing effects of each biomarker on a theoretical exposure-response relationship. Mixed models were also used to estimate the amounts of variation in Phe metabolism to individual OH-Phe isomers that could be attributed to Phe exposure (as represented by U-Phe concentrations) and covariates representing time, hydration level, smoking status, age, and body mass index. Results showed that 1-OH-Phe, (2+3)-OH-Phe, and 1-OH-Pyr were the least-biasing surrogates for exposure to hot asphalt emissions, and that effects of hydration level and sample collection time substantially inflated bias estimates for the urinary biomarkers. Mixed-model results for the individual OH-Phe isomers showed that between 63% and 82% of the observed biomarker variance was collectively explained by Phe exposure, the time and day of sample collection, and the hydration level, smoking status, body mass index, and age of each worker. By difference, the model results also showed that, depending on the OH-Phe isomer, a maximum of 6-23% of the total biomarker variance was attributable to differences in unobserved toxicokinetic processes between the workers. Therefore, toxicokinetic processes are probably less influential on urinary biomarker variance than are exposures and observable covariate effects. The methods described in this analysis should be considered for the selection and interpretation of biomarkers as exposure surrogates in future exposure investigations.

Toraason, M., et al. (2001). "DNA strand breaks, oxidative damage, and 1-OH pyrene in roofers with coal-tar pitch dust and/or asphalt fume exposure." Int Arch Occup Environ Health 74(6): 396-404.

OBJECTIVE: To determine the potential for asphalt fume exposure to increase DNA damage, we conducted a cross-sectional study of roofers involved in the application of roofing asphalt. METHODS: DNA strand breaks and the ratio of 8-hydroxydeoxyguanosine (8-OHdG) to 2-deoxyguanosine (dG) were measured in peripheral blood leukocytes of roofers. In addition, urinary excretion of 8-OHdG and 8-epi-prostaglandin F2alpha (8-epi-PGF) was also measured. The study population consisted of 26 roofers exposed to roofing asphalt and 15 construction workers not exposed to asphalt during the past 5 years. A subset of asphalt roofers (n = 19) was exposed to coal-tar pitch dust (coal tar) during removal of existing roofs prior to applying hot asphalt. Personal air monitoring was performed for one work-week to measure exposure to total particulates, benzene-soluble fraction of total particulates, and polycyclic aromatic compounds (PACs). Urinary 1-OH-pyrene levels were measured as an internal biomarker of PAC exposure. RESULTS: Full-shift breathing zone measurements for total particulates, benzene-solubles and PACs were significantly higher for coal-tar exposed workers than for roofers not exposed to coal tar. Similarly, urinary 1-OH-pyrene levels were higher in coal-tar exposed roofers than roofers not exposed to coal tar. Total particulates or benzene-soluble fractions were not associated with urinary 1-OH-pyrene, but PAC exposure was highly correlated with urinary 1-OH-pyrene. When stratified by 1-OH-pyrene excretion, DNA strand breaks increased in a dose-

dependent manner, and leukocyte 8-OHdG/dG decreased in a dose-dependent manner. Significant changes in DNA damage appeared to be linked to PACs from coal-tar exposure, although asphalt fume alone was associated with a small but significant increase in urinary 1-OH-pyrene and DNA strand breaks. CONCLUSIONS: Results are consistent with previous reports that asphalt or coal-tar exposure can cause DNA damage. Urinary 8-epi-PGF remained relatively constant during the week for virtually all subjects, regardless of exposure indicating that neither asphalt nor coal-tar exposure induces an overt oxidative stress. A small, but statistically significant increase in 8OHdG was evident in end-of-week urine samples compared with start-of-week urine samples in roofers exposed to coal-tar. The increase in urinary 8OHdG coupled with the decrease in leukocyte 8-OHdG/dG, suggests that coal-tar exposure induces protective or repair mechanisms that result in reduced levels of steady-state oxidative-DNA damage.

Trumbore, D., et al. (2011). "Effect of oxidation and extent of oxidation on biologically active PACs in asphalt products." Inhal Toxicol 23(12): 745-761.

Recent studies have reported divergent results in rodent cancer assays using fume condensates from a variety of asphalt products. This paper presents results of a study investigating the role of oxidation, or extent of oxidation, on these findings. Five straight run asphalts, made from widely used crude oils, were used as inputs to both production scale and laboratory oxidation units and processed to a range of softening points used in common roofing products. For each of the five asphalts studied, the oxidation reaction significantly decreased measures of polycyclic aromatic compounds (PACs) that have been linked, previously and in analyses included in this study, to tumor induction in rodent bioassays. Mutagenicity index determined by the modified Ames assay was reduced between 41% and 50% from the input asphalt to the final oxidized product. A fluorescence method tuned to a subset of PAC compounds that have been associated with carcinogenic behavior in mouse bioassays was reduced between 39% and 71%. The decrease was largest in the first quarter of the oxidation reaction. These findings indicate that oxidation, by itself, was not a likely factor in the tumor induction seen in the previous studies. Rather, other factors such as the conditions of fume generation and crude source (coupled with possible differences in distillation endpoints) were more likely to have determined the outcomes. Analyses of previously published data, presented in this paper, suggest that the modified Ames and fluorescence assays are valuable screening tools for use in future health-related asphalt research.

Zhao, H. W., et al. (2004). "Effects of paving asphalt fume exposure on genotoxic and mutagenic activities in the rat lung." Mutat Res 557(2): 137-149.

Asphalt fumes are complex mixtures of aerosols and vapors containing various organic compounds, including polycyclic aromatic hydrocarbons (PAHs). Previously, we have demonstrated that inhalation exposure of rats to asphalt fumes resulted in dose-dependent induction of CYP1A1 with concomitant down-regulation of CYP2B1 and increased phase II enzyme quinone reductase activity in the rat lung. In the present study, the potential genotoxic effects of asphalt fume exposure due to altered lung microsomal enzymes were studied. Rats were exposed to air or asphalt fume generated under road paving conditions at various concentrations and sacrificed the next day. Alveolar macrophages (AM) were obtained by bronchoalveolar lavage and examined for DNA damage using the comet assay. To evaluate the systemic genotoxic effect of asphalt fume, micronuclei formation in bone marrow polychromatic erythrocytes (PCEs) was monitored. Lung S9 from various exposure groups was

isolated from tissue homogenates and characterized for metabolic activity in activating 2-aminoanthracene (2-AA) and benzo[a]pyrene (BaP) mutagenicity using the Ames test with Salmonella typhimurium YG1024 and YG1029. This study showed that the paving asphalt fumes significantly induced DNA damage in AM, as revealed by DNA migration in the comet assay, in a dose-dependent manner, whereas the micronuclei formation in bone marrow PCEs was not detected even at a very high exposure level (1733 mg h/m3). The conversion of 2-AA to mutagens in the Ames test required lung S9-mediated metabolic activation in a dose-dependent manner. In comparison to the controls, lung S9 from rats exposed to asphalt fume at a total exposure level of 479+/-33 mg h/m3 did not significantly enhance 2-AA mutagenicity with either S. typhimurium YG1024 or YG1029. At a higher total asphalt fume exposure level (1150+/-63 mg h/m3), S9 significantly increased the mutagenicity of 2-AA as compared to the control. However, S9 from asphalt fume-exposed rats did not significantly activate the mutagenicity of BaP in the Ames test. These results show that asphalt fume exposure, which significantly altered both phases I and II metabolic enzymes in lung microsomes, is genotoxic to AM and enhances the metabolic activation of certain mutagens through altered S9 content.

CPWR THE CENTER FOR CONSTRUCTION RESEARCH AND TRAINING

www.cpwr.com • www.elcosh.org